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I. INTRODUCTION

Most states have enacted Statutes which regulate the disposal of waste waters, particularly as regards their disposal to lakes and streams. These laws necessarily affect many dairies, since in most instances small dairies either discharge their wastes directly into lakes and streams or into drainage ways that drain into these waters. To a large number of small dairy plants, the costs of conventional waste treatment facilities are prohibitive.

A brief summary of the Wisconsin Statutes, which are similar to those of many states, emphasizes the problem with which the small dairy operator is confronted. These laws provide for the general supervision and control by the State Board of Health of all waters within the state. Under the enactment, a water pollution committee was appointed. The duties of this committee are to exercise general supervision over the administration and enforcement of all laws relating to the pollution of the surface waters of the state. Specifically, these duties are: (1) To study and investigate pollution problems and make recommendations, (2) to carry on scientific research to discover methods for the disposal or treatment of industrial wastes to control pollution of the surface waters of the state, (3) to issue general orders regulating the installation and operation of disposal facilities within the state, (4) to issue special orders directing owners to secure operating results within a specified time that the committee may prescribe, (5) to inspect and investigate and to insure compliance with general and special orders, (6) to study interstate pollution problems and enter into agreements, on approval of the governor, with other states.

Seventy-one milk plants in Wisconsin had disposal systems completed prior to January 1, 1956. Methods of treatment included irrigation, hauling, chemical, soil absorption, and aeration.

The problem of milk plant waste disposal in any state having an appreciable amount of dairying is exemplified by the situation in Wisconsin. According to licenses issued by the Wisconsin Department of Agriculture there were 1,766 operating dairy plants in Wisconsin on December 31, 1954. Of this number 491 were licensed to produce more than one product. According to the number of licenses issued, 1,064 were cheese factories, 374 milk distributing plants, 236 butter factories, 251 receiving stations, 186 ice cream factories, 125 cottage cheese factories, 111 powdering operations, 75 condensories, 16 manufacturers of processed cheese, 16 whey drying operations, and 3 that produced cheese food compounds.

Factories licensed to make American Cheese make up about 80 per cent of the cheese plants in the state. These plants are generally located in three areas, namely, the southwest, the east-central, and the north-central parts of Wisconsin. Wisconsin produces about one-third of the nation's Swiss Cheese supply. Swiss cheese factories are concentrated in Green, Lafayette, Dane, Iowa, Barron, and Grant counties.

Brick and Munster cheese factories in Wisconsin are located mainly in two areas. The southwest area includes parts of Lafayette, Iowa, Dane, and Green counties. The other area centers in Dodge County.

Butter plants, powdering operations, and condensories are widely scattered throughout the state with very few located in the northern counties.

Market milk plants are located in every county of the state with more plants being located in areas of high population. It should be noted also that the milk plants are concentrated in the areas of good agricultural soils, i.e., the finer textured soils such as silt loams and clay loams. Waste disposal by means of sprinkler irrigation is more of a problem on the fine textured soils than on the sands because of the much lower permeability of the former soil.

Glossary

gpd – gallons per day
gph – gallons per hour
gpm – gallons per minute
gpad – gallons per acre per day
psi – pounds per square inch
BOD – biochemical oxygen demand
H.P. – horsepower
ppm – parts per million
mgd – million gallons per day
COD – chemical oxygen demand
mg/1 – milligrams per liter
ppm – parts per million

II. LITERATURE REVIEW

This review covers the disposal by spray irrigation of both cannery and dairy wastes, since the process is essentially the same for each.

The first recorded instance of waste disposal by spray irrigation occurred at Hanover, Pennsylvania, in 1947 (31). The Hanover Canning Company disposed of all its processing wastes, ranging from 190,000 to 440,000 gpd by spraying it on an area of 200 acres. The water was given preliminary treatment through a one-eighth inch revolving screen and settling tanks which provided a minimum detention time of 1½ hours. One portable gasoline pump and one electric pump delivered the waste to 62 Skinner irrigation mozzles. A line pressure of 90 psi resulted in a coverage of 280 square feet per nozzle.

In 1950 the Lakeside Packing Company (5, 6, 23) at Plainview, Minnesota, began disposing of processing wastes on a 108 acre area. By rotating the areas sprayed, an application rate of about 3 inches per day was maintained on the rolling silt loam soil which was underlaid with clay. The waste passed through a 20 mesh rotary screen to a 150,000 gallon wet well and then to the 3/16" and 7/32" nozzles. A 50 H.P. 700 gpm pump supplied a pressure of 35 psi at the nozzles which spread 14.2 gpm each.

The Green Giant Company (5, 6, 21, 26) at Blue Earth, Minnesota, started spray irrigation in 1951. They sprayed 600,000 – 700,000 gpd on 90 acres of grass and woodland pasture of heavy loam underlaid with clay. The waste passed through a 10 mesh screen, to a wet well, and then to sprinklers with 7/32" and 11/32" nozzles rated at 20 to 30 gpm. Application rates were approximately 0.5 inches per hour over an 8 to 12 hour period.

At Oakfield, Wisconsin (26), the Mammoth Spring Canning Company installed a spray irrigation system to handle a waste flow of about 100 gpm on seven acres of silt loam soil covered with grasses. Twenty sprinkler heads at 60 foot intervals were rated at 25 gpm at 45 psi. The sprinklers were moved on alternate days.

The Michigan Fruit Canners Incorporated (10) at Fennville, Michigan, started spray disposal in 1950. A volume of 300,000 gallons of waste per day were spread over eight acres of rolling Ottowa loam blended into Saugatuck sand which was covered with trees and grass. Four spraying positions were used with two day rest periods.

At Austin, Indiana, the Morgan Packing Company (20) began year-round spray irrigation in 1952. About 1.3 million gallons, per 16 hour day, were applied to 240 acres of Kentucky fescue at a rate of 0.44 inches per hour from 22 sprinklers, each distributing 33 gpm.

Sanborn (27) described a typical small cannery irrigation system which sprayed 126,000 gpd over seven level acres of wheat, brome, fescue, and orchard. A 10 H.P. 150 gpm pump supplied the waste to 10 sprinklers at 45 psi. The sprinklers were moved on alternate days.

Hipke Foods Incorporated (1) at Mount Calvary, Wisconsin, made use of plastic pipe to carry the waste to 6 sprinklers spaced at 30 foot intervals. The system handled 4,300 gph at 25 psi.

The most publicized system is that employed at Seabrook Farms in New Jersey (15, 38). Spray irrigation is used to dispose of a daily flow of 5 to 10 million gallons of process water. The waste was sprayed over an 84 acre wooded area of Sassafras loamy sand at a rate of about 6.4 inches per day. The waste flowed 9,000 feet through a ten foot canal and was then distributed to sprinklers which discharged 20,000 gph per nozzle at 60 psi. Each portion of land received waste for an 8 hour period, followed by a 24 hour recovery period. The total cost of the system was about $150,000. Operation of the system was carried on from May 1 to December 15. Table I summarizes the flow and strength characteristics of the waste on a yearly basis.

TABLE I*

Year		Flow mgd	B.O.D. ppm	B.O.D. lbs	B.O.D. lbs/Acre/Day
1950	avg	6.000	191	9,000	276.0
	max	11.875	1,050	61,000	2,110.0
1951	avg	5.78	312	10,000	220.0
	max	10.68	645	27,000	1,367.5
1952	avg	4.45	121	5,150	117.5
	max	10.00	380	10,500	540.0

* Reproduced from Sewage & Industrial Waste, *26*, 135 (1954)

Spray irrigation of dairy wastes followed that of cannery wastes by about two years. The first noted installation of the former was used in 1949 at Donelson, Tennessee (4). The Swiss Farms disposed of about 12,000 gallons of milk waste daily on a seeded 2 acre pasture. A luxurious forage crop developed.

In southern New Jersey a dairy plant (27) having a milk intake of about 90,000 pounds per day disposed of about 75,000 gallons of waste water daily on 48 acres of light sandy loam having a cover crop of hay. Irrigation facilities included a septic tank, earthen basin, 15 H.P. pump rated at 200 gpm, irrigation main line of 5 inch aluminum pipe, and fifty-nine 3/4-inch sprinkler nozzles rated at 10.5 gpm at 45 psi. The entire system cost $15,000.

Another dairy plant also in New Jersey (27) disposed of 80,000 gpd on 100 acres of pasture. The topsoil consisted of 10 to 12 inches of clay loam over clay and gravel. Thirty, 3/4-inch sprinkler nozzles were spaced at forty foot intervals. No difficulty was experienced with winter operation. The cost of the system amounted to $5,200.

An Ohio milk plant (14) applied waste to the soil at a rate of 400,000 gpd on 40 acres of pastureland. Lateral and riser pipes were insulated for winter operation. The total cost of the system was $5,000.

At Fort Wayne, Indiana (27), a bottling plant sprayed 70,000 gallons of waste on 40 acres of grassland. Sprinklers were spaced at 60 foot intervals.

At Shirley, Indiana (7,18), 3,000 gallons of waste per acre per day were sprayed onto a tiled field. No indication of the milk waste was found in the underdrainage. Whey of 30,000 ppm B.O.D. strength was applied at a rate of 5,000 gpd on 30 acres. Initially bare ground existed, but a heavy growth of weeds developed and thrived.

From 3,000 to 6,000 gallons of milk waste per day were sprayed on grassland and tobacco fields at Owenton, Kentucky (7). The tobacco yield was increased 20 per cent as a result of the irrigation. Some trouble was experienced during the winter as a result of freezing and splitting of pipes. Plastic pipe failed after one month's use and was replaced by steel pipe which was buried.

At Alexandria, Tennessee (7, 18), 12,000 gallons of dairy waste per day were sprayed on 3½ acres. Polythylene pipes failed after one year's usage and were replaced by steel.

The Northermost spray irrigation site reviewed was located at Berwick, Ontario. Operation began there in 1952. A waste flow of 10,000 gallons with a B.O.D. of 3,000 ppm were spread daily on 2½ acres of pastureland from April through October. During the winter digestion tanks were used.

Kuhlman (13) briefly discussed spray irrigation of dairy wastes in Germany and described a new system developed there. In this system small enclosed tanks (1.5M^3) of acid resistant aluminum were used instead of large tanks and the wastes pumped automatically to the irrigation field.

In a discussion of spray irrigation of dairy waste, McKee (19) considered waste volume, rather than concentration, to be the limiting factor in determing the area of land needed. Two factors of importance are the separation of wastes and the rigid control of the amount of wash water. He described seven typical installations in the U.S. and Canada that have had successful operation. The daily waste volume at these plants ranged from 6,000 to 75,000 gallons, the rate of application from 1,670 to 7,300 gpad and the spray area from 2 to 45 acres. The three most important factors which influence dosage of waste on the field are: (1) slope of ground (less than 6 per cent), (2) type of soil (clay, loam, etc.), and (3) type of cover crop. He indicated that a spray irrigation system can operate successfully with more whey in the waste than can be tolerated in a trickling filter or activated sludge treatment plant.

Trebler and Harding (34) reviewed recent trends in the field of dairy industry wastes including a discussion of separation of wastes, by-product utilization, waste composition, pretreatment, flow measurement, sampling, and methods of treatment, including irrigation.

Haack (8) raised the question of the danger of infection of cattle by virulent tubercle bacilli that may be sprayed on growing grasses with this method of disposal. About 0.1 per cent of the milk enters the waste untreated; thus, there is a possibility of virulent bacteria in the waste, and these bacteria may persist for fairly long periods in the grass. He concluded that the question cannot be answered with the present data.

Henry, et. al. (9) reported on spray irrigation studies and stated that 40 inches or more of sewage effluent can be applied to a crop of Reed canary grass during a normal growing season. Crop yields are substantially increased by plant nutrients in the effluent. Drainage waters from the soil irrigated with sewage effluent did not increase the coliform index of the nearby stream.

In a discussion on irrigation of industrial wastes, Schraufnagel (28) noted that about 30 milk plants in Wisconsin were using spray irrigation. Original costs, excluding land, ranged from $300 for a small factory using old equipment and doing most of the contrusction, to a high of $5,000. The disposal rates ranged from 2,000 gpad on extremely heavy soils to 15,000 gpad on favorable soils. Six factories in Southern Wisconsin continued spray operation throughout the winter with difficulty. Most of the vegetation, under the ice cover that formed, was killed off and reseeding was necessary in the spring.

Sharatt, et. al (29) reported on the use of whey as a source of plant nutrients. A ton of whey was found to contain about a dollar's worth of nitrogen, phosphorus, and potassium. Whey applications did not have a detrimental effect on the pH of soils which were well limed and near neutral. Alfalfa tolerated a limited amount of whey but did not benefit much from it; grasses appeared more tolerant and whey applications increased their growth.

Webber (37) indicated that soil surveys are useful in selecting suitable areas for spray irrigation. Laboratory tests suggested include infiltration, permeability, and storage capacity. Transpiration studies were also considered to be important. He noted that the cover crop uses the most moisture when growing, thus cutting of the grass before maturity was recommended.

Williamson (39) reported on spray irrigation of food processing wastes and made the following recommendations: 1. Carefully select soils; 2. Keep heavy equipment off irrigated areas; 3. Harrow soil in spring; 4. Keep good cover crop on soil; 5. Exclude sanitary wastes; 6. Divert storm water; and 7. Use as small a reservoir as possible to prevent stagnation.

Parker (24) discussed spray irrigation of tannery waste and noted that heavy application killed weeds, trees, and other growth. Moderate applications caused alfalfa to turn brown in several weeks, but orchard brome grass and timothy appeared to be satisfactory cover crops.

From the installations reviewed it appears that dairy wastes generally range from three to fifteen times the B.O.D. strength of cannery waste, but because of lower volumes, the B.O.D. loadings per acre are lower than for cannery wastes. B.O.D. loadings compare as follows: Cannery 207 to 1,840 pounds per acre per day, and dairy 167 to 695 pounds per acre per day.

Table II summarizes the data on application rates and waste volumes for many of the plants described.

TABLE II

	Location	Flow Rate Mgd	Application Rate in/day	B.O.D.(5 Day) ppm	B.O.D. lbs/acre/day	Soil Type
CANNERY	Hanover, Pa.	.19	1.4-3.4	200	798-1,840	
	Plainview, Minn.		3.0			Silt Loam (Tampa-Jordan Series)
	Blue Earth, Minn.	.60	4.0-6.0			Heavy Loam
	Oakfield, Wisconsin					Silt Loam
	Fennville, Mich.	.30	0.35			Saugatuck Sand
	Unknown	.13	1.3			Silt-Loam
	Seabrook Farms	5-10	6.4	212	207	Sassafras Loamy Sand
DAIRY	Southern New Jersey	.075	0.15			Light, Sandy Loam
	New Jersey	.080	2.85			Clay Loam
	Ohio	.40				
	Fort Wayne, Ind.	.070	0.17			
	Shirley, Ind.	.15	0.008-0.009			
	Alexandria, Ind.	.018	0.03			
	Tennessee Swiss Farms	.012	0.11	660	167	
	Berwick, Ontario	.01	0.08	3,000	695	

III. SELECTION OF SITES

Spray irrigation appears to hold promise as an effective means for the disposal of wastes from dairy plants in view of the encouraging results already reported in the literature. The method is likely to be particularly useful for small plants in areas where land is available. To study the method a Research and Marketing Act contract between the University of Wisconsin and the United States Department of Agriculture was made. The purpose of the study was to determine the effectiveness of spray irrigation as a method for the disposal of dairy plant wastes. The project included studies of both the soils and engineering aspects of the problem.

The initial emphasis was to observe existing spray irrigation procedures and facilities in milk products factories located in Central Wisconsin. The second and final phase of the project was to evaluate this method, and where warranted, make recommendations on the proper installation and operation of spray irrigation as a method of disposal for dairy wastes. These recommendations were based on results obtained in the initial phase of the project through the observation of the existing sites. Various application rates were applied on particular soil types, in conjunction with a rigorous study of resulting effects on the soil.

Since the amount of water that can be applied to any given area depends on certain specific soil properties as well as on the water consumed by the crop, the sites for the study were carefully selected so as to provide a wide range of soil conditions. In this regard consultation was had with a representative of the Committee on Water Pollution of the State of Wisconsin, because at certain of the installations variations in operation of the irrigation systems were required during certain phases of the project.

Five sites were selected. Their proximate locations are indicated in Figure 1.

DESCRIPTION OF SOILS STUDIED

Description of soils being irrigated by the factories included in this study are as follows:

The soil types irrigated at Plant A varied from Miami to Dodge silt loams. The surface soil was a friable silt loam and graded into a more dense clay loam in the subsoil. A calcareous sandy till occurred at a depth varying from 18 in. (Miami) to over 3 ft. (Dodge). The amount of water in excess of crop needs that could be applied to this soil was dependent upon the permeability of the subsoil which was fairly good.

At Plant B the field irrigated was flat bottom land. Several feet of recent deposit derived from the upland cultivated fields overlayed the old soil. The texture of the surface 2 ft. varied from sandy loam to silt loam which graded into a sand or sandy loam below. Peat occurred at a depth of about 4 ft. This soil had a high permeability.

The soil irrigated at the Plant C was Hixton sandy loam. The surface 2 ft. consisted of sandy loam which was underlain by sand grading into decomposing sandstone. Water movement through this soil was good.

The field irrigated at Plant D was elevated only a few feet above the water level of a near-by creek. Consequently, the water table was only a few feet below the surface in much of the field, and in some of the depressional areas standing water occurred at least during part of the year. The soil was derived from eroded material from the surrounding uplands. There was a silt loam cap varying in depth from 6 to 12 in. which was underlain by loam. The subsoil was mottled and bluish gray in color indicating water logged conditions. This site was selected because of its poor irrigation possibilities.

At Plant E the field irrigated was Dodgeville silt loam. The surface soil, 8 to 10 in. thick, was a dark silt loam. The subsoil, which varied from 18 in. to 2 ft. in depth, was a silty clay loam. Below this was a layer of compacted clay which graded into broken limestone rock. Solid rock occurred at a depth varying from 4 to 5 ft. Since this was a fairly shallow soil overlying solid rock, water logging became a problem under intense irrigation.

PROXIMATE LOCATIONS OF IRRIGATION SYSTEMS STUDIED

Figure 1

IV. GENERAL INFORMATION OBTAINED AT EACH SITE

Soon after selecting the sites topographic surveys of the areas were made and topographical maps prepared. The maps showed variation in topography at each site and were used to permanently locate soil borings as they were made. Copies of these maps appear in Figures 2 through 4.

Pertinent general information was obtained at each plant from questionnaries completed by each operator. The questionnaires covered the following items:

1. Name of plant
2. Location of plant
3. Amount of each product produced
4. Milk intake
5. Type and capacity of equipment: Can washer; holding tank; cheese vats; butter churners; ice cream machines; coolers; curing tanks, and cream separators
6. Floor space
7. Depth of well and type of water system
8. Cost of irrigation system
9. Arrangement utilized to secure land for irrigation project
10. Compounds used and their composition: Soap, detergents; scouring compounds, and curing aids
11. Schedule of plant operations

Supplementary information regarding the irrigation system was also obtained for each of the sites under study. Included in these data were the following items:

1. Size of wet well or sump
2. Type of pump and motor used
3. Piping used for permanently fixed portion of system
4. Valve arrangements
5. Size and type of portable piping
6. Number, size, type, and spacing of spray nozzles

A rain gage and thermometer were installed at each site. Daily readings by the plant operator furnished satisfactory temperature and precipitation records.

V. WASTE SAMPLING PROCEDURES AND METHODS OF FLOW DETERMINATION

Grab samples taken at the beginning of the study indicated that great variations existed in the concentration and in the volume of the waste over a twenty-four hour period. Examples of these wide variations are indicated in Figures 5 through 14. These variations pointed out the need for reliable methods of flow measurements and reliable procedures for obtaining twenty-four hour composite samples. The usual hand sampling method was considered to be impractical because of the labor required. Automatic samplers were not available in sufficient numbers and were too prone to clog to be satisfactory. The development of simple trouble free samplers was undertaken early in the project.

The final form of these samplers consisted basically of an adjustable 2-inch sheet metal splash plate attached to a trough leading fo a funnel in a refrigerated sample bottle. The splash plate was mounted over the open top of a one-gallon can having a bottom drain connected to the wet well. A one half-inch line from the discharge side of the pump allowed a small stream of waste to fall on the splash plate, which was so adjusted that during a twenty-four hour period about 2 liters were diverted to the sample bottle. The remainder of the waste from the sampling line drained into the attached can and thence into the wet well. A valve in the waste sampling line permitted control over the waste flow to the splash plate. A plug type valve was found to be more satisfactory than globe or other valves because of less frequent clogging. Despite the use of this type of valve it was found necessary to keep the valve approximately half open to prevent clogging. At this valve position uncontrollable splashing occurred on the splash plate. To control the splashing a 90° elbow was attached to the end of the sampling line and a 1/8 inch hole drilled into the sampling line directly above the splash plate. With this arrangement a portion of the waste splashed over the plate, and the remainder flowed from the elbow into the drain can. By rotating the elbow more or less waste could be diverted to the splash plate. The portion of the waste falling on the splash plate distributed itself between the funnel in the sample bottle and the drain can, depending on the adjustment of the splash plate. In this way satisfactory control of sampling was possible. The 2-liter sample bottle was packed in ice in a picnic type cooler. The cover of the cooler was drilled to permit the insertion of the stem of the funnel into the sample bottle.

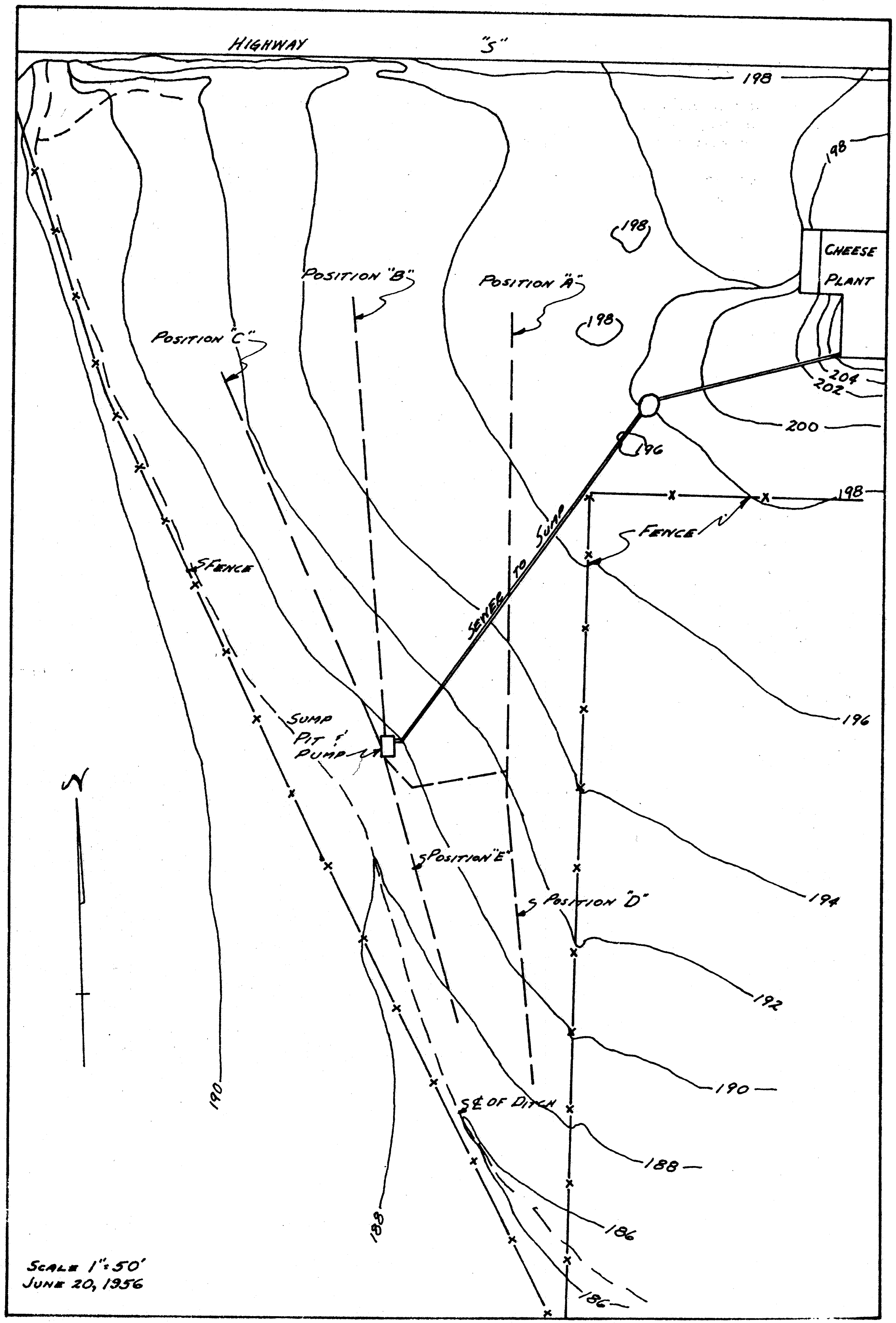


Figure 2 Topographic Map of Spray Irrigation Field – Plant "A"

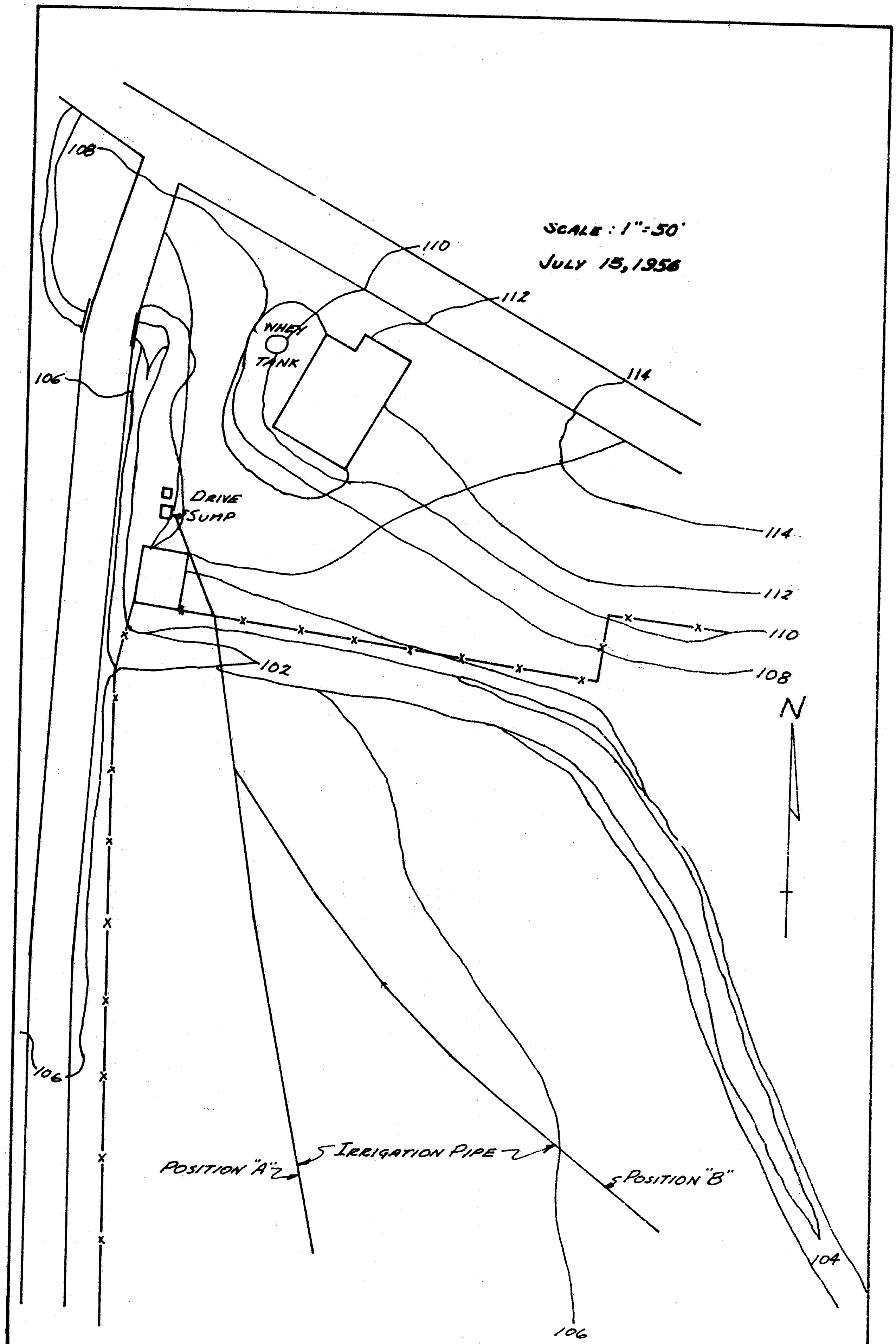


Figure 3 Topographic Map of Spray Irrigation Field – Plant "B"

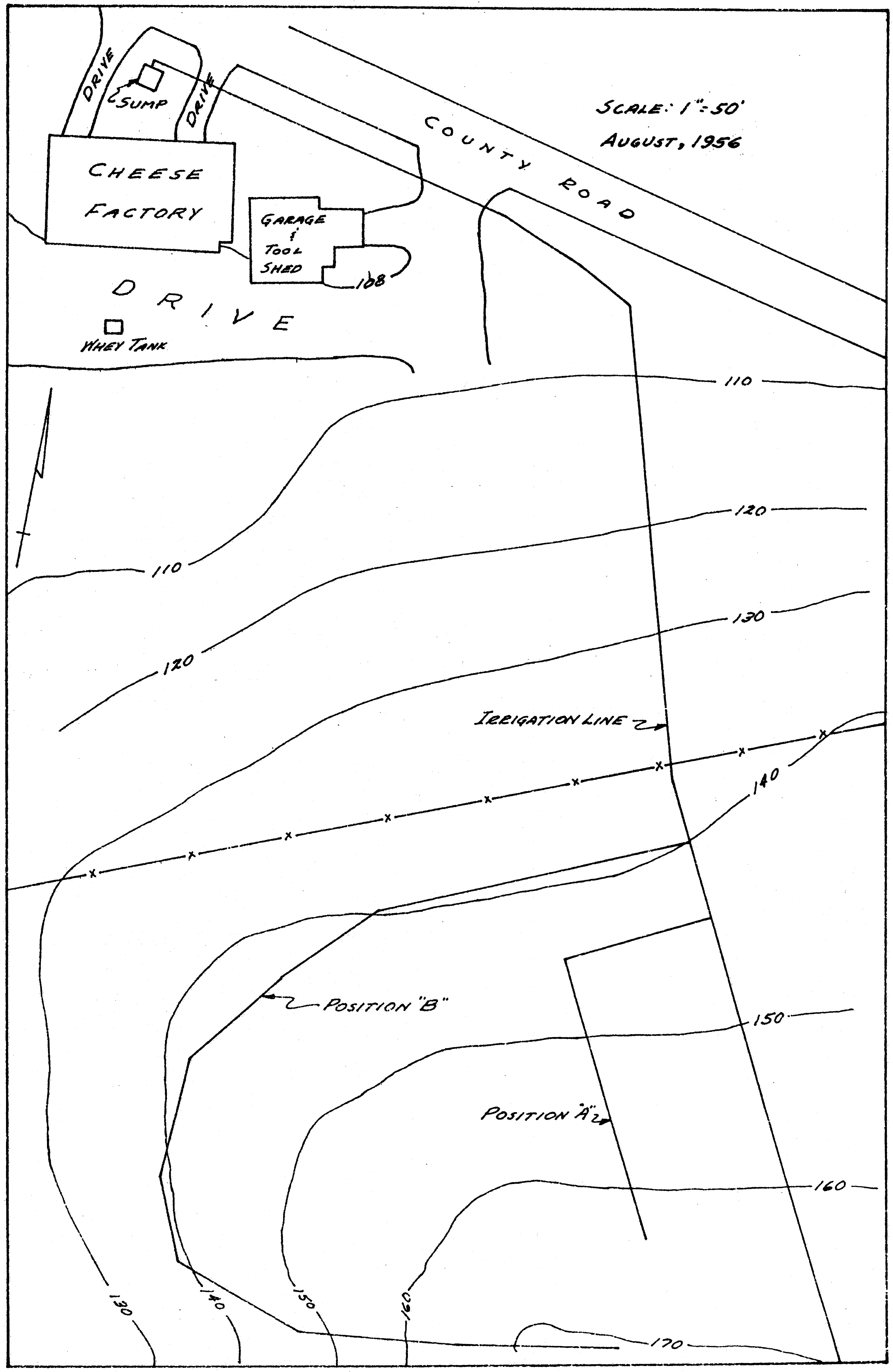


Figure 4 Topographic Map of Spray Irrigation Field – Plant "C"

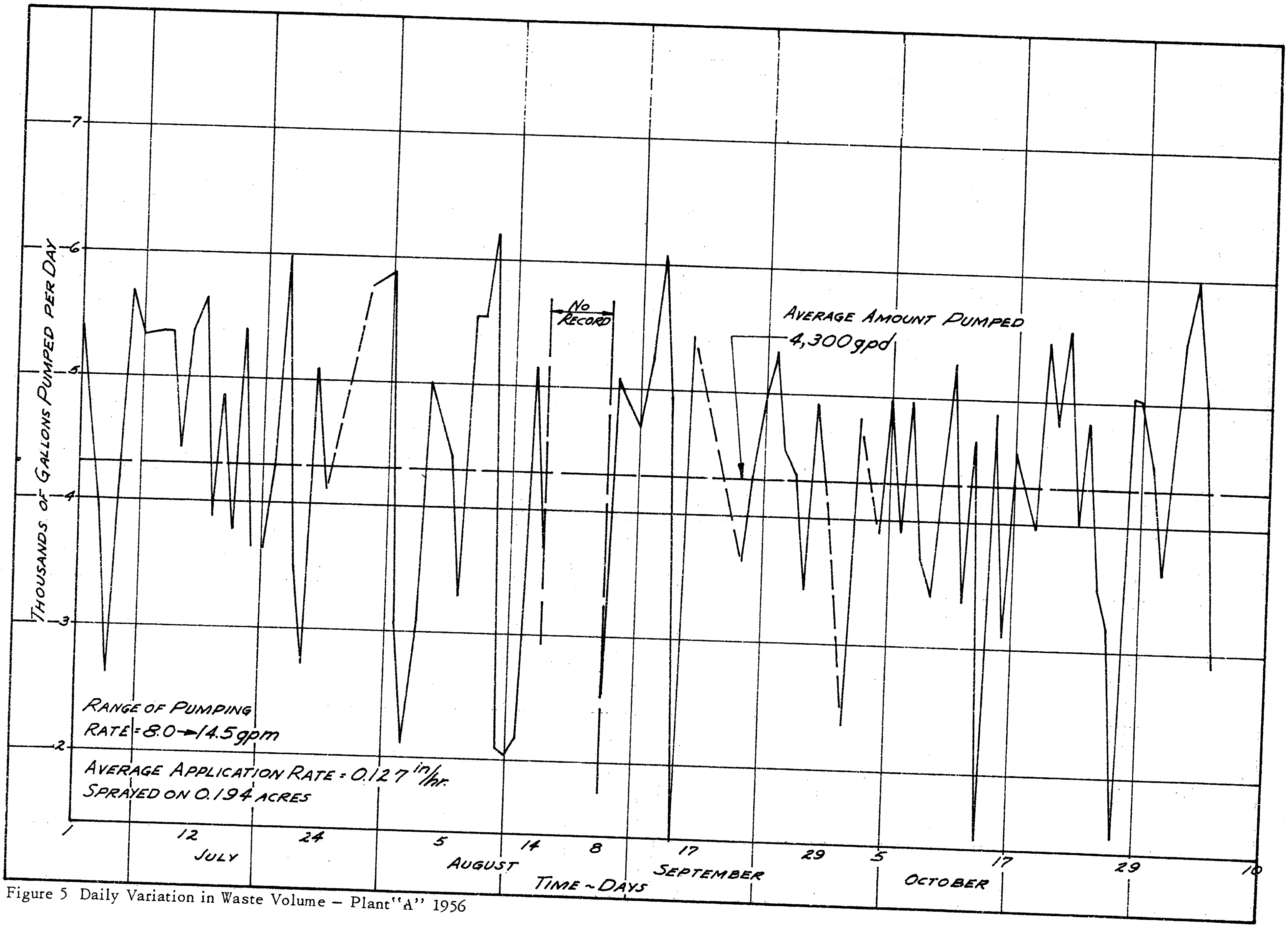


Figure 5 Daily Variation in Waste Volume – Plant "A" 1956

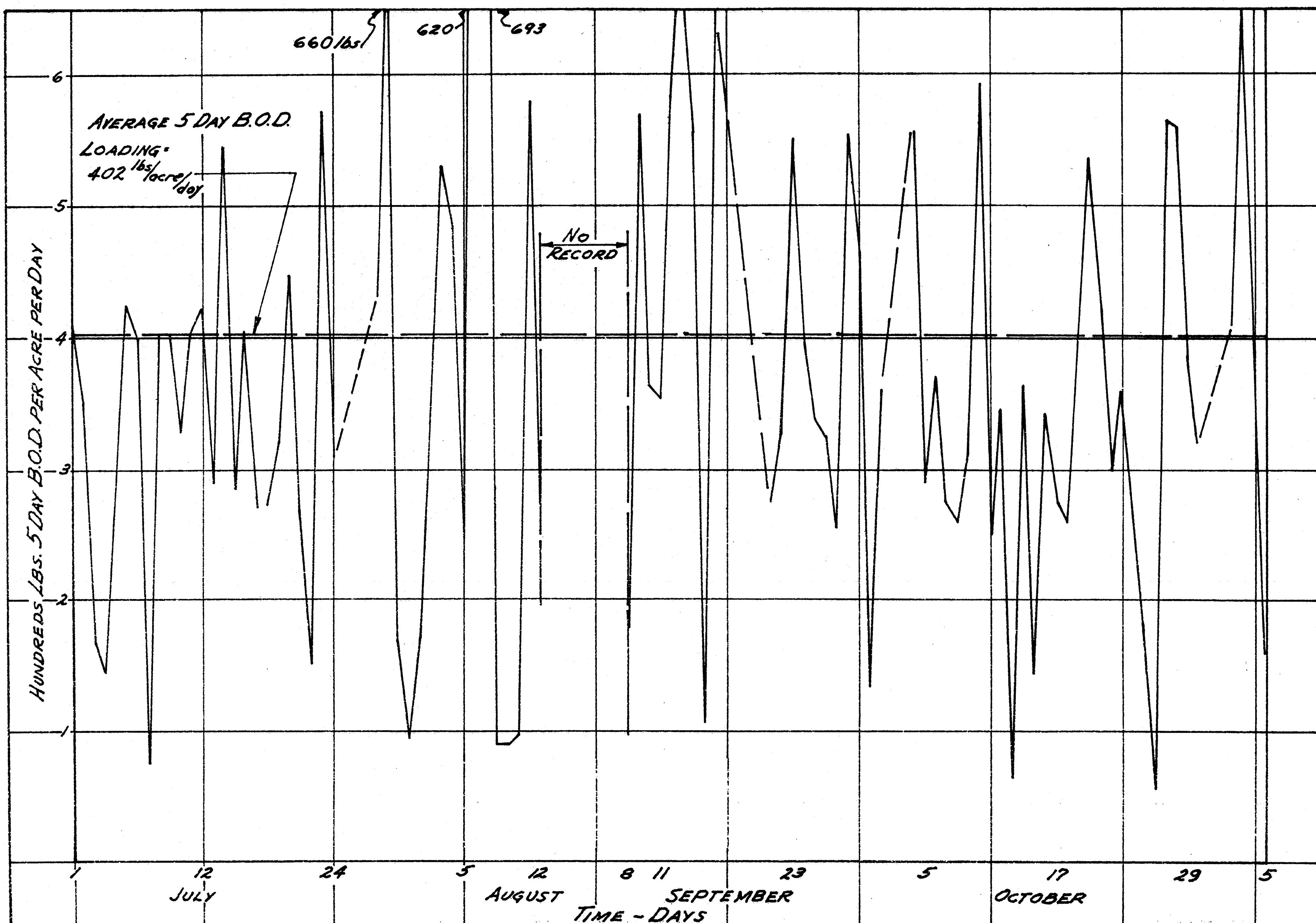


Figure 6 Variation in 5 Day B.O.D. Loading – Plant "A" 1956

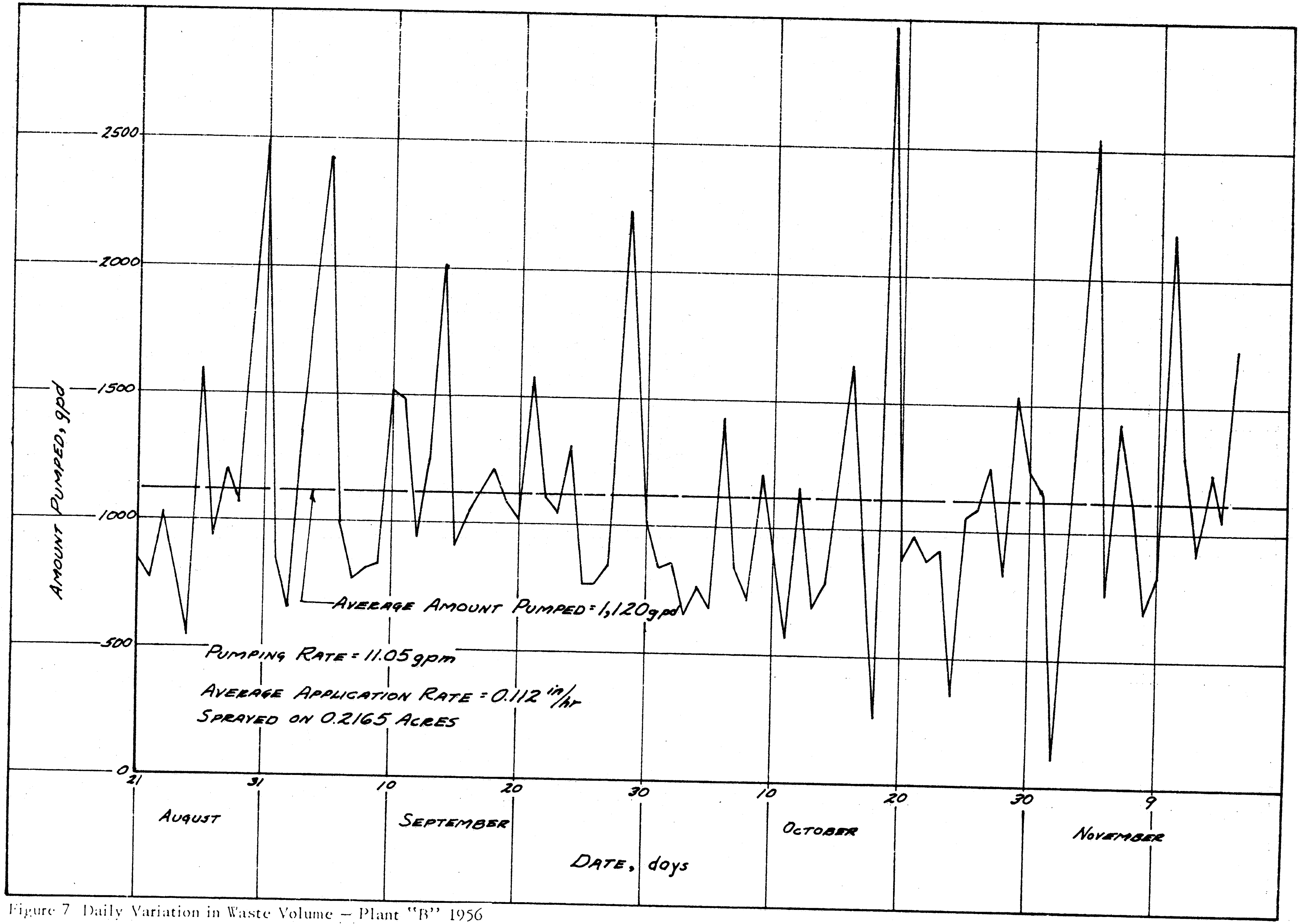


Figure 7 Daily Variation in Waste Volume – Plant "B" 1956

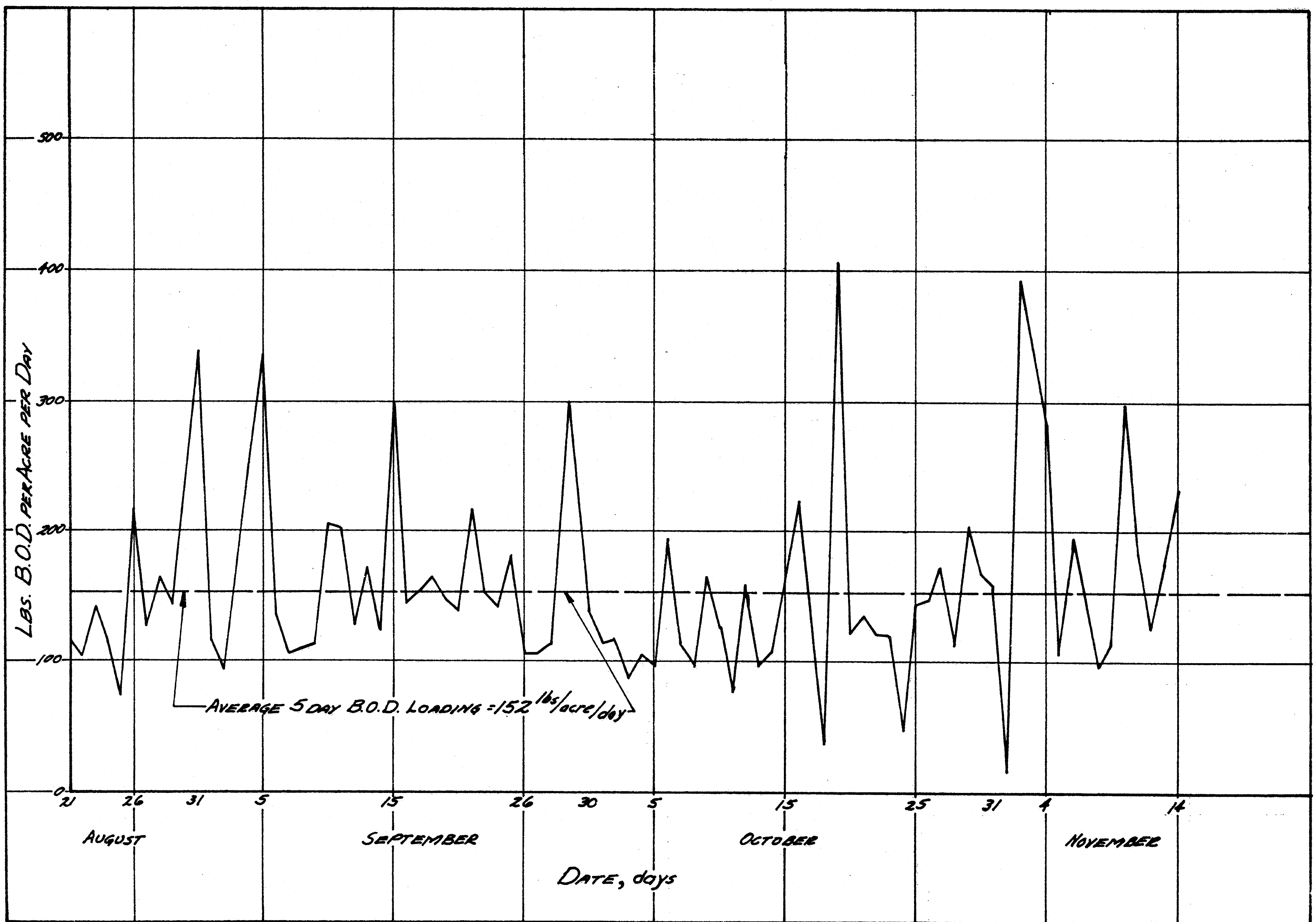


Figure 8 Variation in 5 Day B.O.D. Loading – Plant "B" – 1956

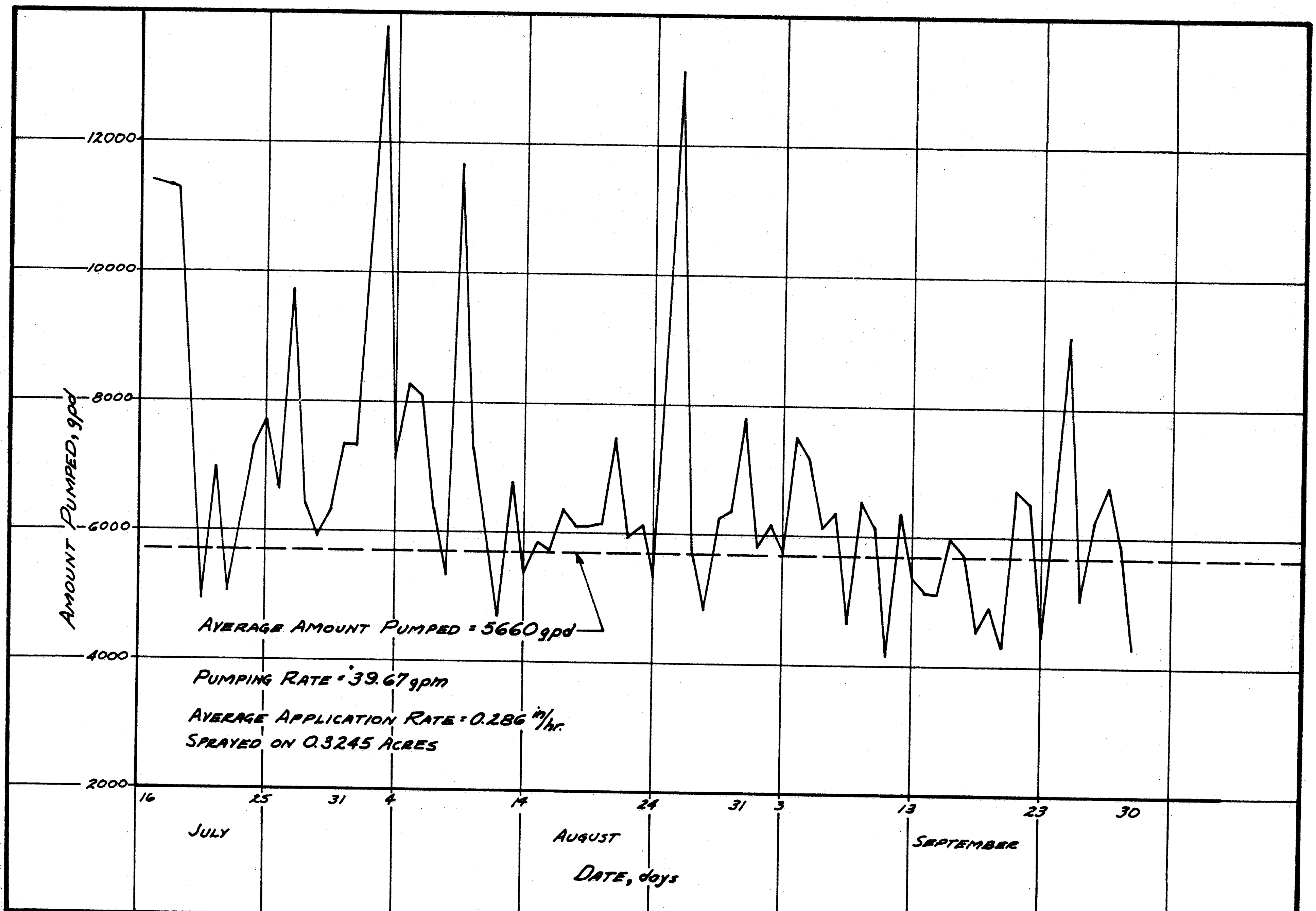


Figure 9 Daily Variation in Waste Volume – Plant "C" – 1956

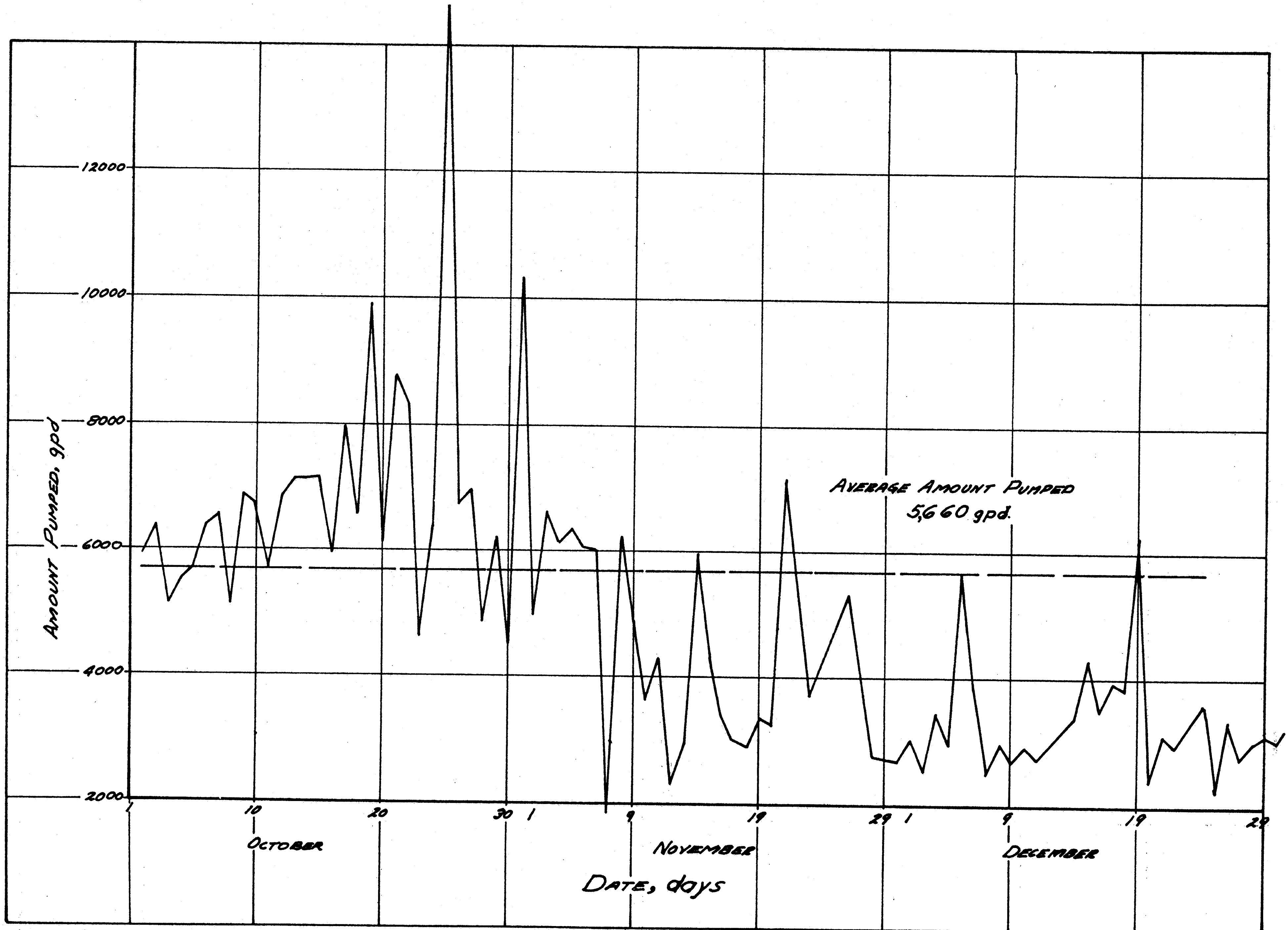


Figure 9 (Cont.) Daily Variation in Waste Volume – Plant "C" – 1956

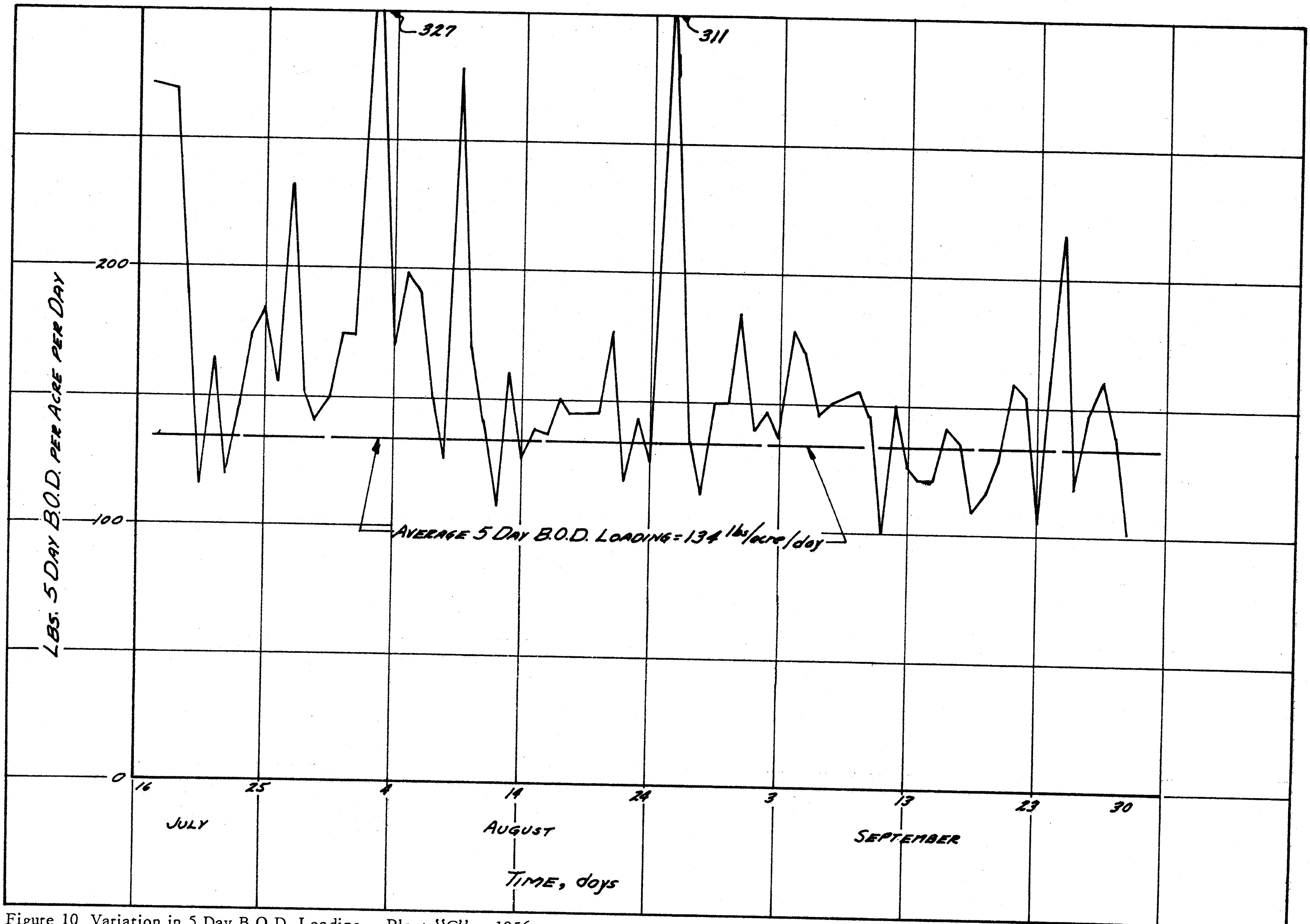


Figure 10 Variation in 5 Day B.O.D. Loading – Plant "C" – 1956

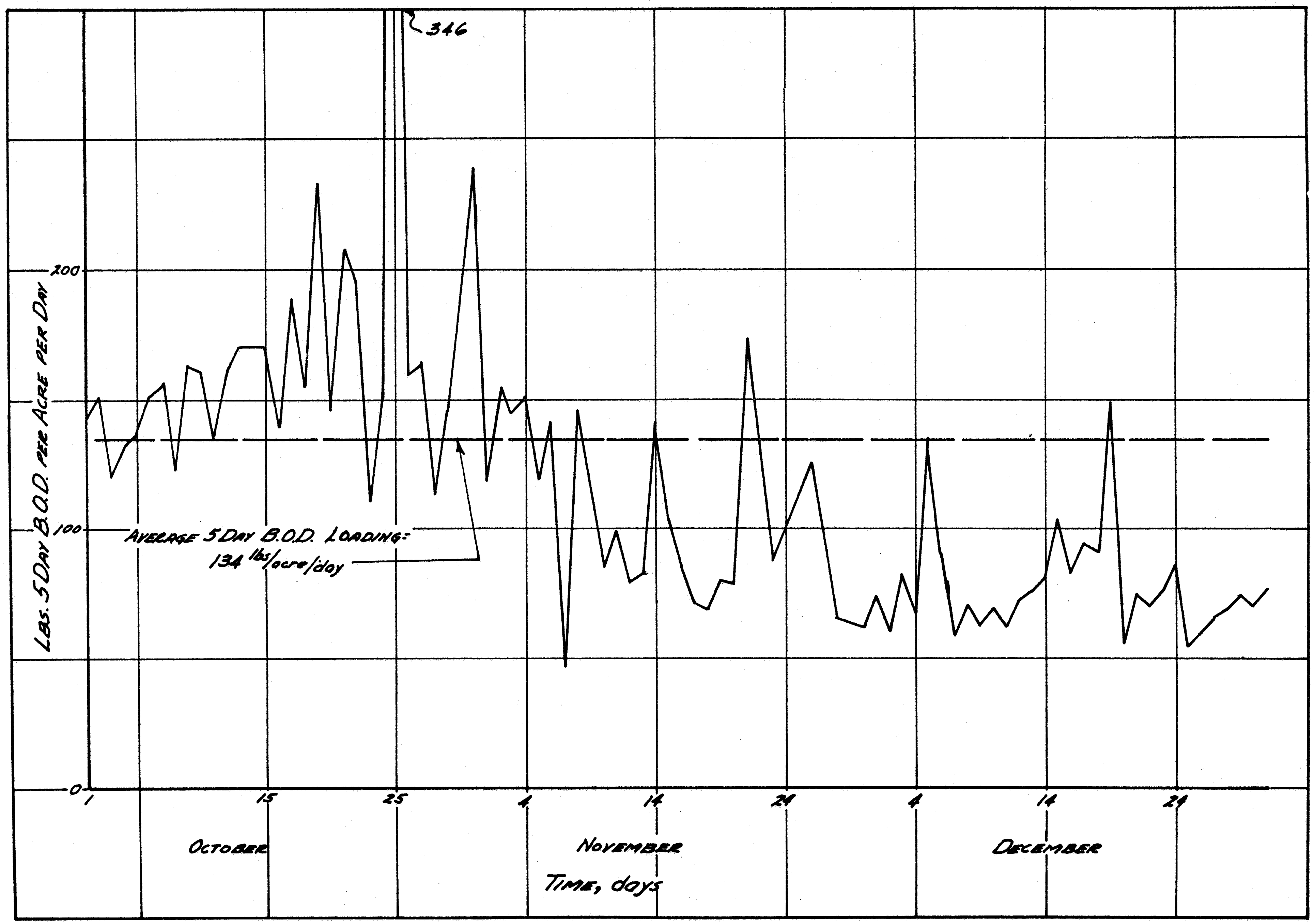


Figure 10 (Cont.) Variation in 5 Day B.O.D. Loading – Plant "C" – 1956

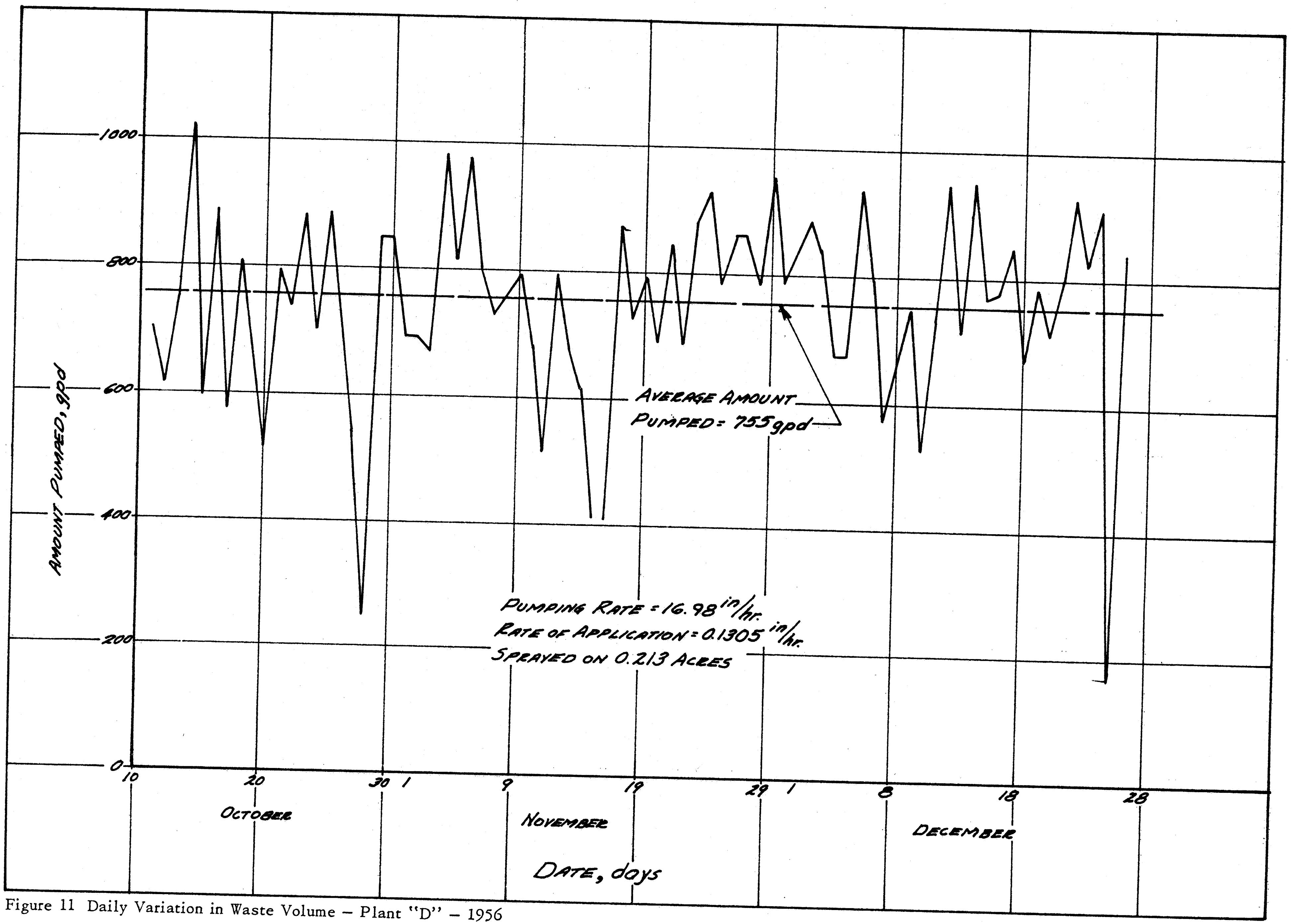


Figure 11 Daily Variation in Waste Volume – Plant "D" – 1956

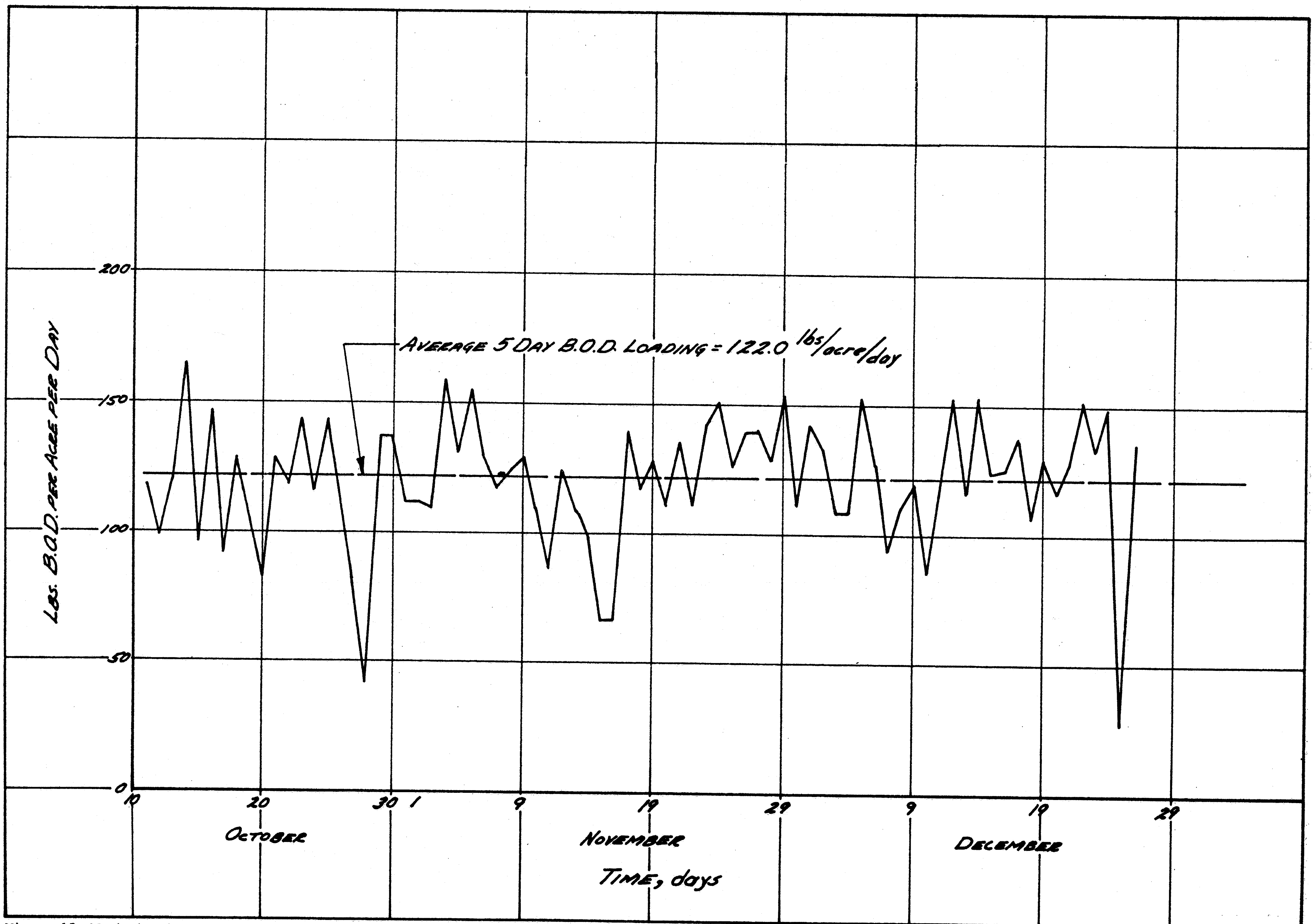


Figure 12 Variation in 5 Day B.O.D. Loading – Plant "D" – 1956

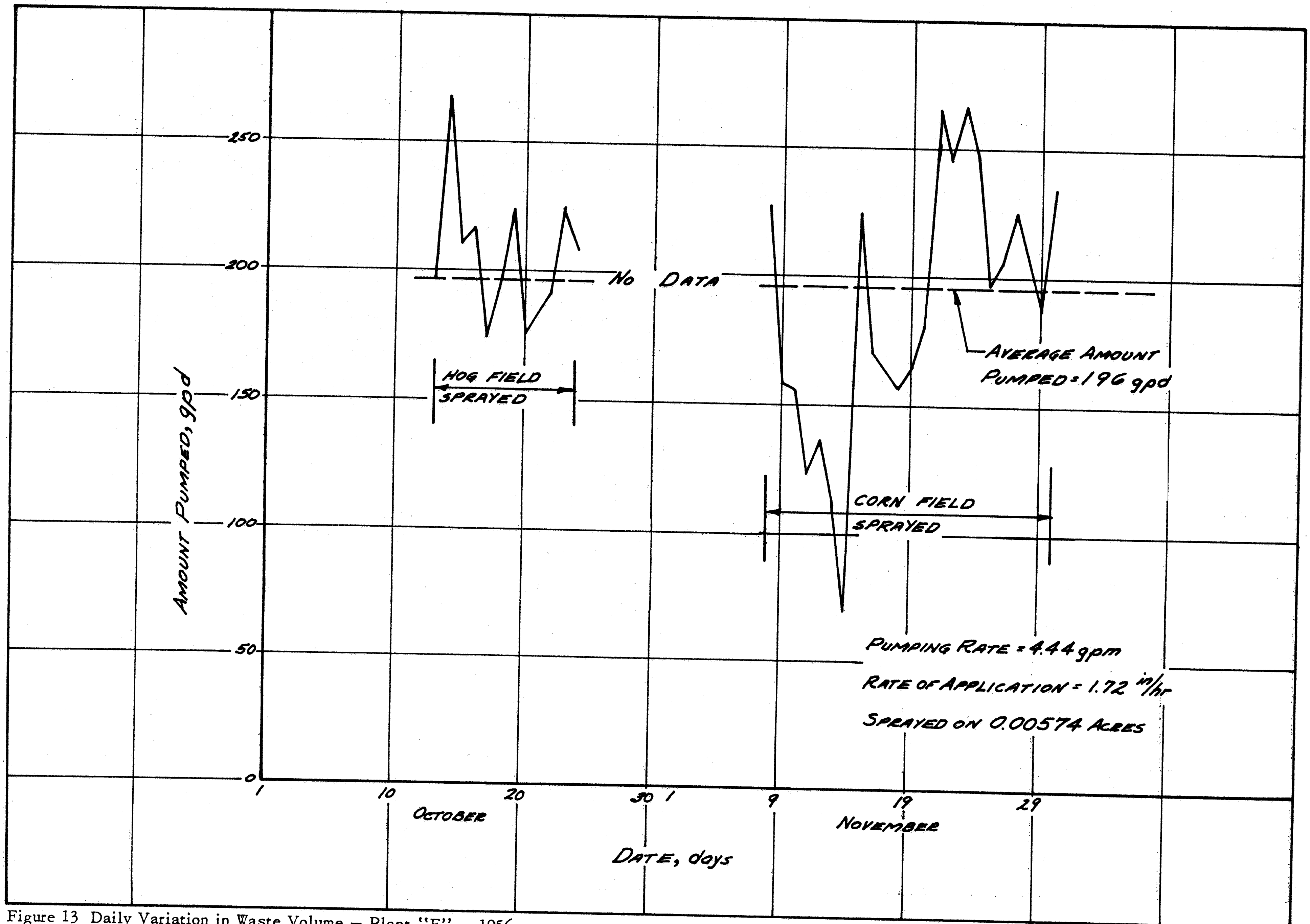


Figure 13 Daily Variation in Waste Volume – Plant "E" – 1956

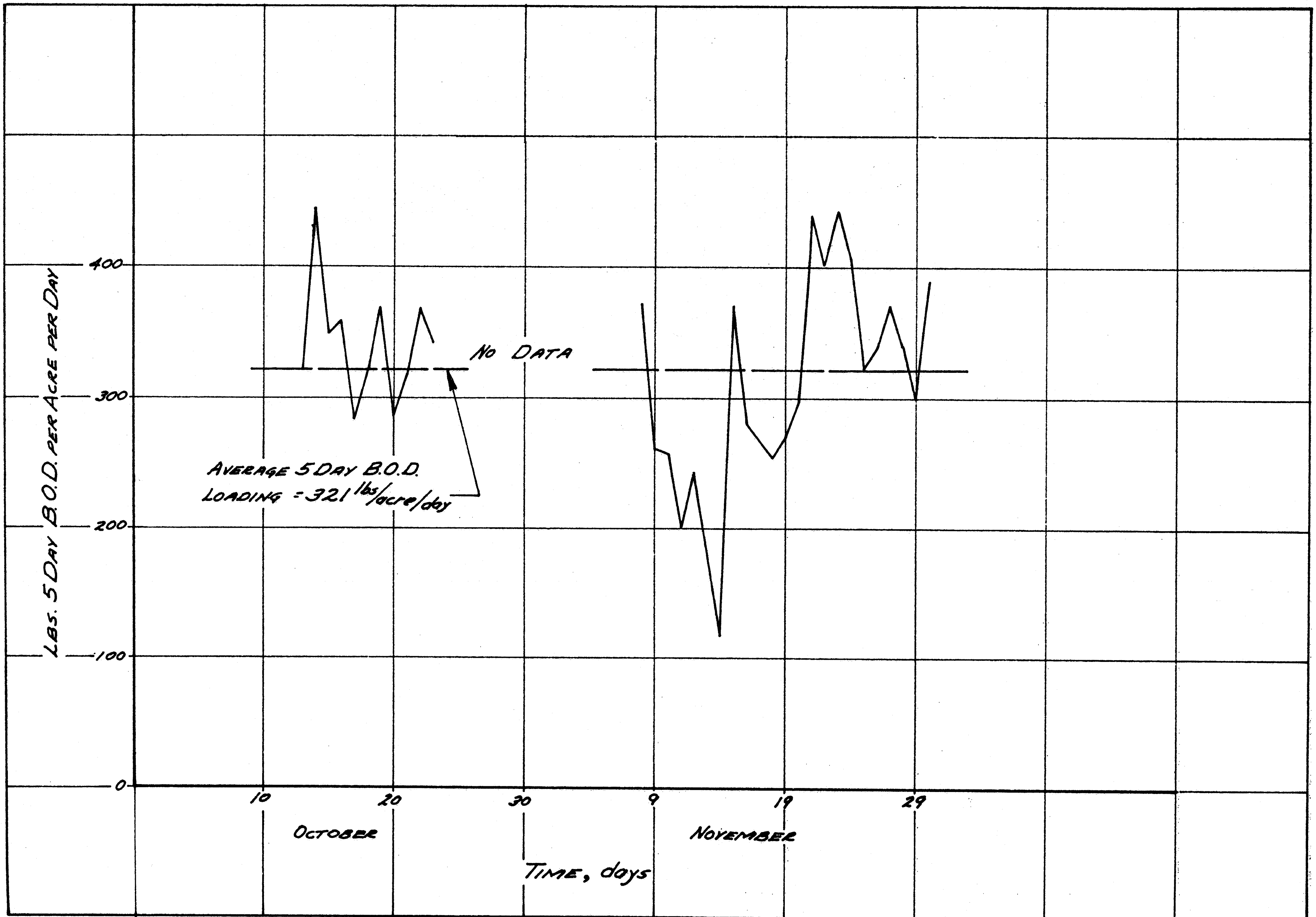


Figure 14 Variation in 5 Day B.O.D. Loading – Plant "E" – 1956

A sketch of the sampling device is shown in Figure 15.

Twenty-four hour surveys were made at Plants A, and C. Hourly samples were obtained of the waste flowing to the wet well and of the waste being pumped to the irrigation field. pH, temperature, and dissolved oxygen were obtained in the field and BOD determinations were made at the laboratory. Figures 16 and 17 illustrate the variations in strength of these wastes over the twenty-four hour periods.

Various methods of flow measurement were considered. The wet well arrangements in general did not lend themselves to the application of measuring devices such as weirs; thus consideration was given to the coordinate method (2) illustrated in Figure 18. This method made use of depth measurements in the outfall pipe to the wet well, and of measurements of the vertical and horizontal components of the trajectory of the waste from the end of the pipe. The wide variations in the volume of flow made the use of this method impractical for determining total amount of waste, but it was useful in making occasional checks on the flow rates from the plant proper.

Attempts were made to determine the total flow by catching, weighing and timing the flows from the individual nozzles of the sprinkler system. The frequent clogging of the nozzles altered the flow rates thus producing unreliable values. This method was abandoned except for occasional checks.

The final method was based on the hours of pump operation and the discharge rate of the pump as determined from drawdown rates in the wet well. The surface area of the wet well was carefully determined at each site and the withdrawal rates for each pump computed from liquid level changes in the wet well while the pump was in operation. These drawdown tests were made frequently and mean values obtained for each pump. Some variation in discharge was found because of clogged nozzles but the mean value was considered to be representative of the average discharge.

The hours of pump operation were obtained from clocks wired in parallel with the pump. The clocks were located adjacent to the pump in a closed compartment, readily available to the plant operator who recorded the hours of clock operation once each twenty-four hours and then reset the clock to 12:00. At the time of taking and recording the clock reading the operator also recorded the temperature, rainfall for the previous 24 hours, various observations on the weather, unusual plant operation, and position of the irrigation system. At most of the irrigation sites the cooperation of the operator in recording these data was excellent, but in some instances the data forms were incomplete or incorrect.

The irrigated areas were determined by measuring the diameters of the individual spray areas at each site. With these data the application rates were readily computed.

Milk spillage and drippage in cheese factories are approximately 0.5 per cent to 2 per cent of the milk intake, thus most of the waste volume is the plant used water. In order to check the waste volumes water meters were installed on the pipes leading from the wells at each plant. Weekly readings of the meters were compared with flow measurements based on time of pump operation. In general, fairly good correlation of the two methods was found. However, during some seasons of the year a high percentage of the whey was discharged with the waste, thus periodically upsetting the correlations.

VI. DETERMINATIONS MADE ON WATER AND SOILS

The sanitary analyses made on the milk wastes consisted of 5-day biochemical oxygen demand, chemical oxygen demand, pH, alkalinity, ammonia nitrogen, organic nitrogen, residue on evaporation, and suspended solids.

Chemical analyses of the waste included determination of potassium, calcium, magnesium, sodium, chloride, and phosphorus.

Analyses of soil samples included determinations of bulk density, sodium, potassium, calcium, magnesium, acid soluble phosphorus, water soluble chloride, pH, percentages of sand, silt, and clay, and percentage pore space. Since the analyses were made using the generally accepted methods, the procedures are not described here but are briefly outlined in the appendix.

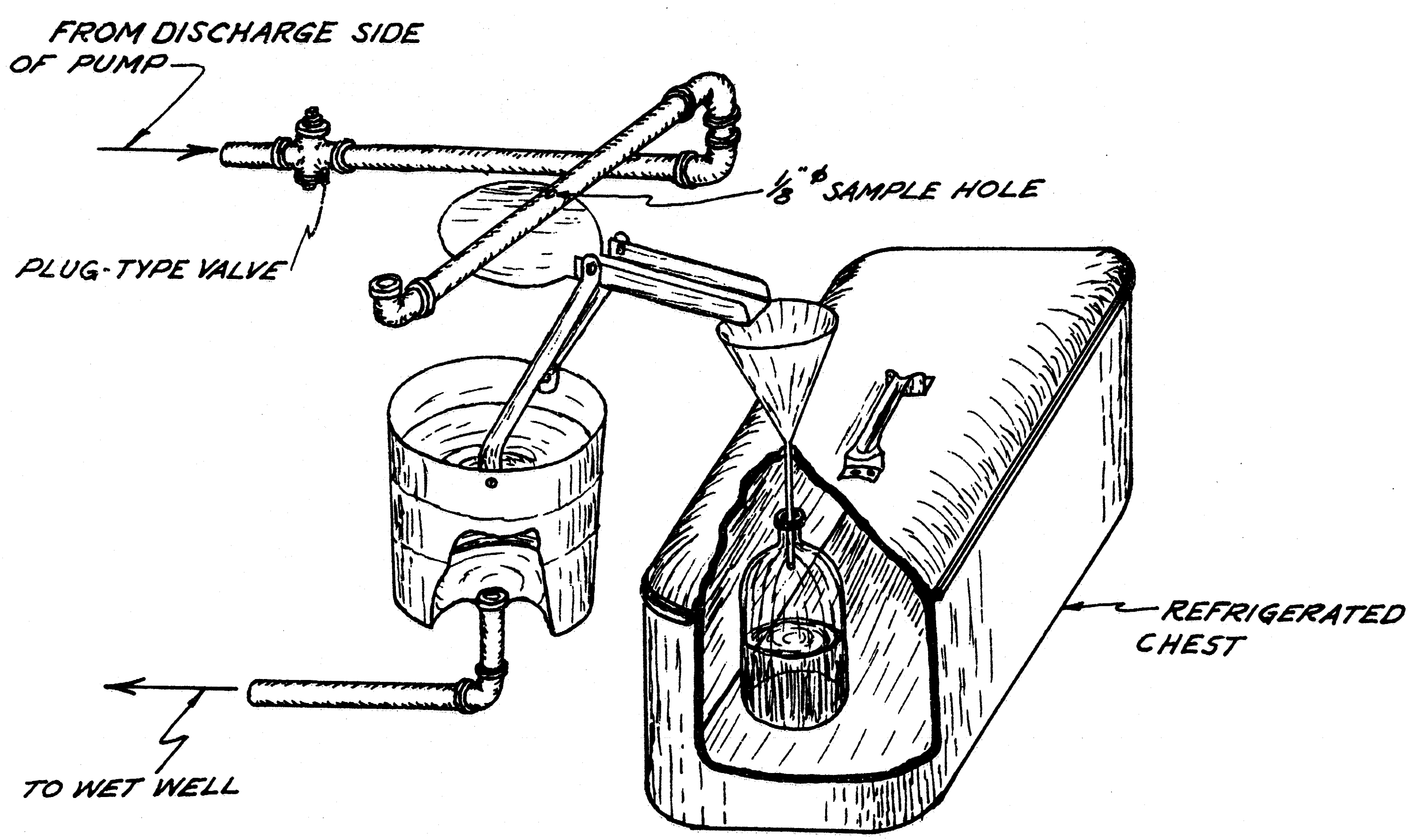
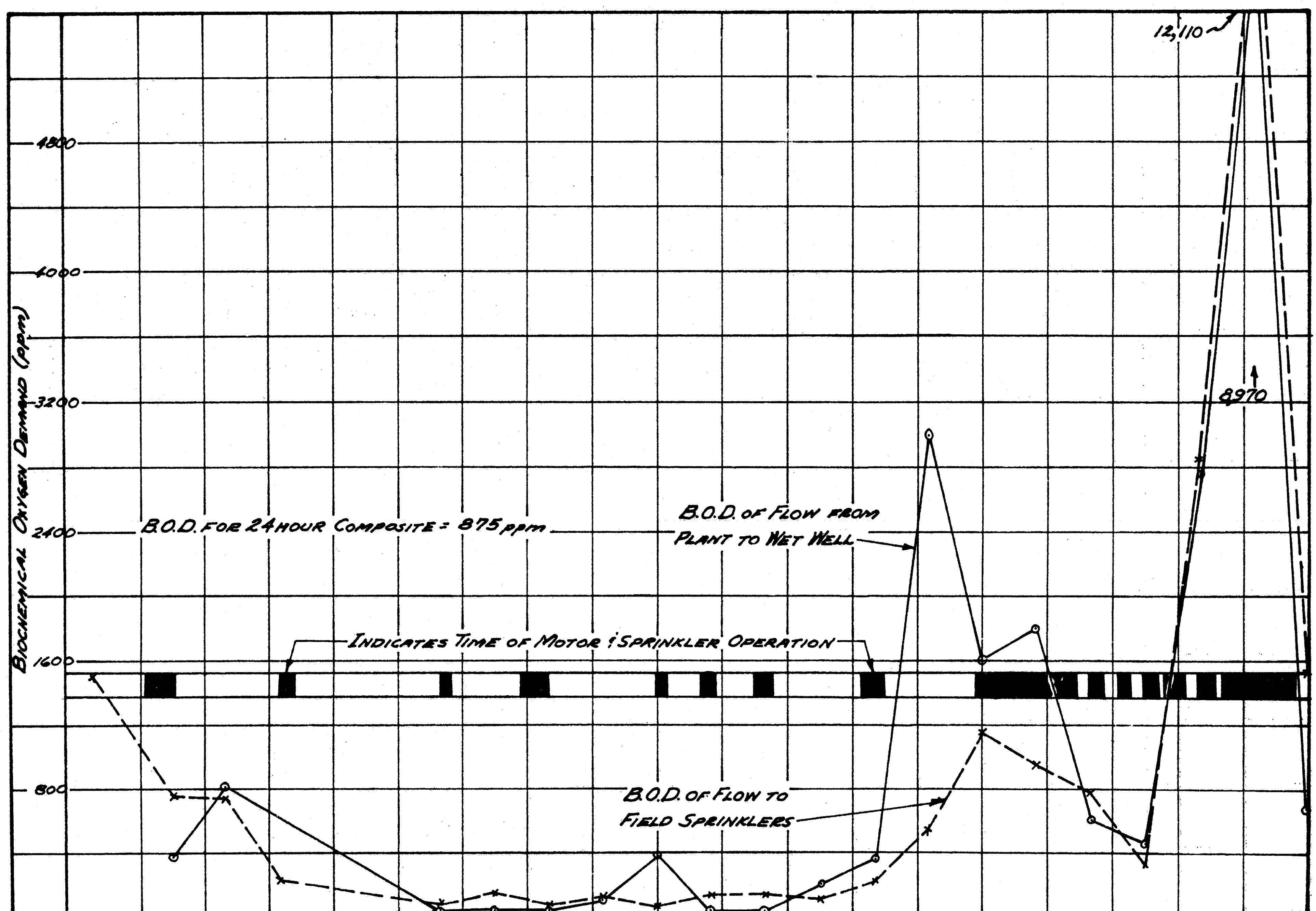


FIGURE 15 SAMPLING DEVICE FOR OBTAINING COMPOSITE SAMPLE.



12,110
8970
4800
4000
3200
2400
1600
800
Biochemical Oxygen Demand (ppm)
B.O.D. for 24 hour Composite = 875 ppm
B.O.D. of Flow from Plant to Wet Well
Indicates Time of Motor & Sprinkler Operation
B.O.D. of Flow to Field Sprinklers
4
PM
8
PM
12
AM
4
AM
8
A.M
12
P.M.
Time

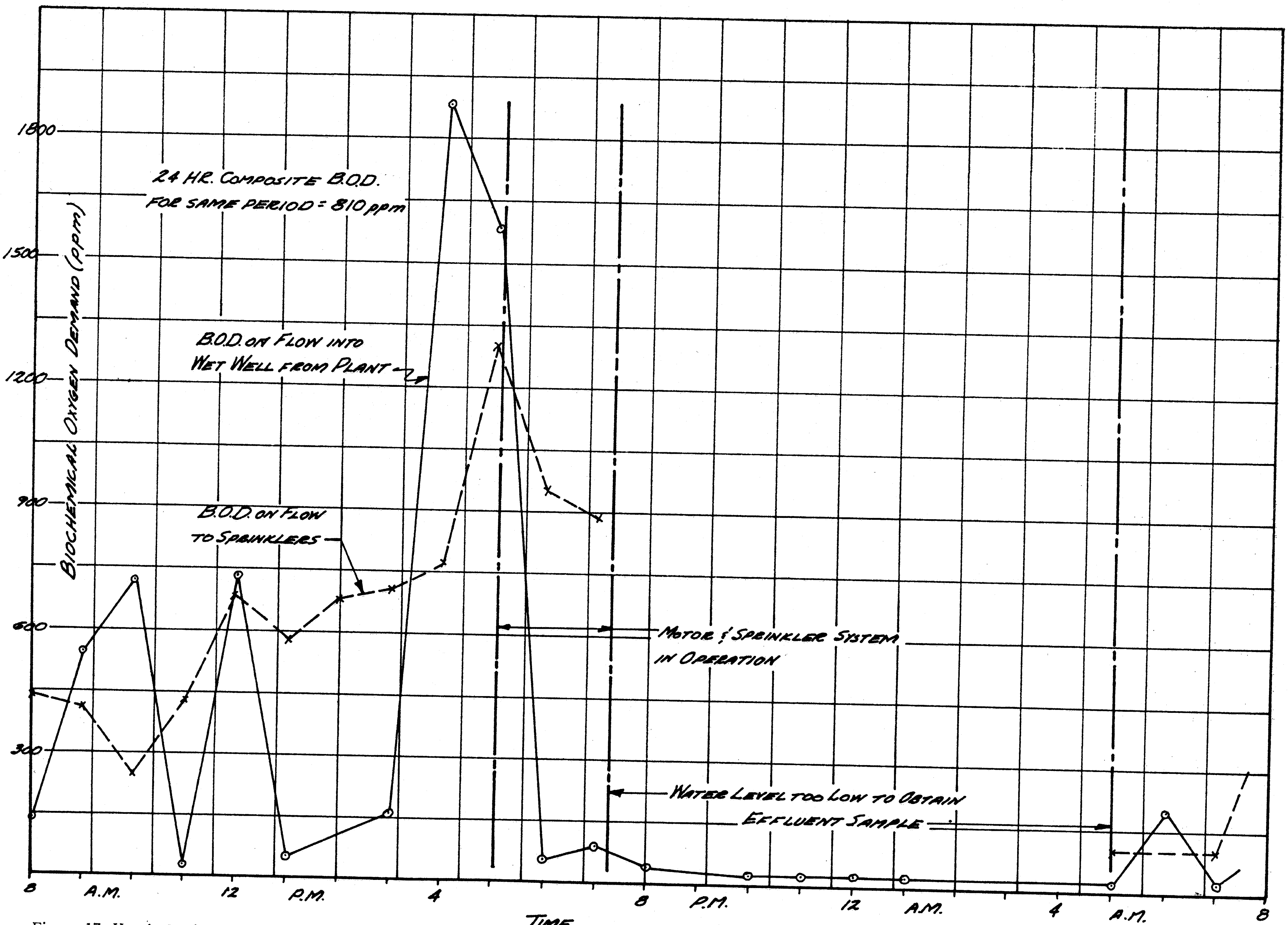
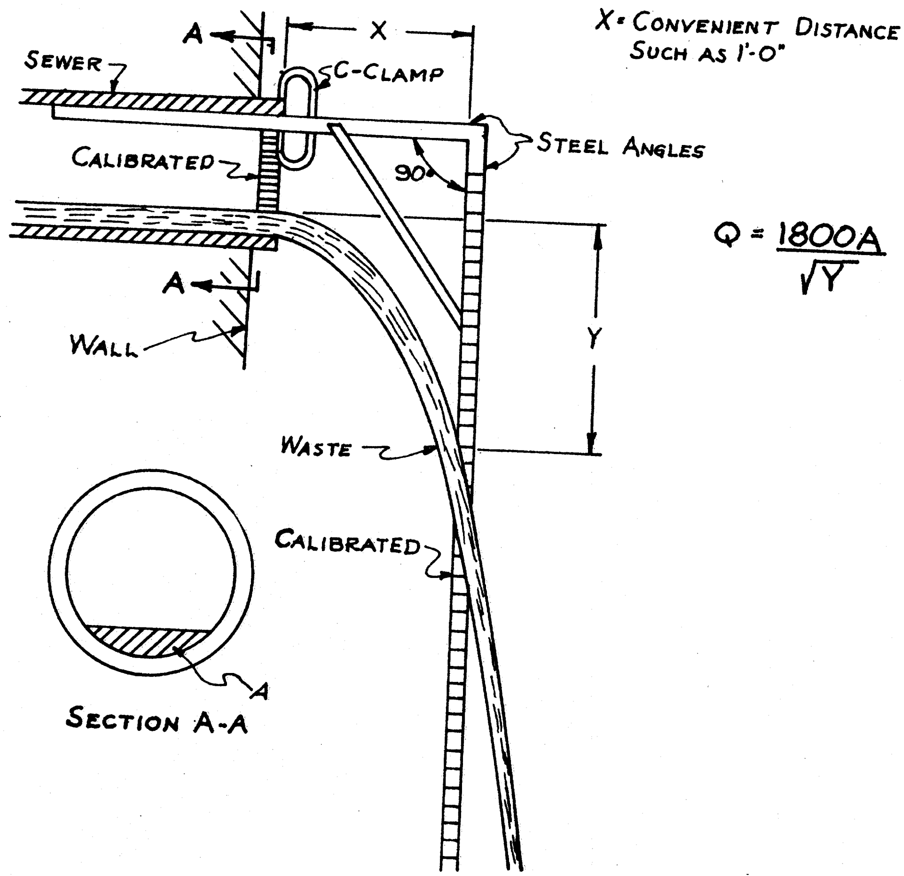


Figure 17 Hourly Variation in B.O.D. – Plant "C" – 24 Hour Survey August 23, 1956



Factors for Calculation of Wet Area of Cross Section of a Sewer

d/D	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.0000	.0013	.0037	.0069	.0105	.0147	.0192	.0242	.0294	.0350
.1	.0409	.0470	.0534	.0600	.0668	.0739	.0811	.0885	.0961	.1039
.2	.1118	.1199	.1281	.1365	.1449	.2535	.1623	.1711	.1800	.1890
.3	.1982	.2074	.2167	.2260	.2355	.2450	.2545	.2642	.2739	.2836
.4	.2934	.3032	.3130	.3229	.3328	.3428	.3527	.3627	.3727	.3827
.5	.3927	.4027	.4127	.4227	.4327	.4426	.4526	.4625	.4724	.4822
.6	.4920	.5018	.5115	.5212	.5308	.5404	.5499	.5594	.5687	.5780
.7	.5872	.5964	.6054	.6143	.6231	.6319	.6405	.6489	.6573	.6655
.8	.6736	.6815	.6893	.6969	.7043	.7115	.7186	.7254	.7320	.7384
.9	.7445	.7504	.7560	.7612	.7662	.7707	.7749	.7785	.7816	.7841
1.0	.7854									

d = depth of water in sewer D = diameter of sewer

Reprinted from "How Can Plant Losses Be Determined?", Bloodgood, D.E., and Canham, R.A., Proceedings of the Third Industrial Waste Conference Purdue University, 1947.

Figure 18 Coordinate Method for Flow Measurement

VII. IRRIGATION SYSTEMS

It was noted from the data obtained in the original plant surveys that considerable variation occurred in equipment used, in cost, and in application rates among the various plants studied. However, these installations were generally typical of spray irrigation systems found in this section of the country.

The general design of spray irrigation systems may be represented by the following flow diagram:

Plant sewer ⟶ screen ⟶ wet well ⟶ pump ⟶ pipe line ⟶ distribution line ⟶ sprinklers.

The following discussion covering each of the units of a spray irrigation system is based on information gained during this study plus additional information obtained from various other studies.

The plant sewer conducts waste waters from floor drains, sinks, equipment washers, and other areas from which the milk waste originates, to the screen. It is desirable to locate the screen and wet well so that gravity flow occurs in the sewer. In some plants cooling waters are emptied to this sewer while in other plants these relatively clean waters are sent to a stream or roadside ditch, usually with little harmful results. Such a diversion frequently results in a considerable decrease in the volume of waste to be irrigated. The whey produced in cheese plants is usually returned to the farms for hog feeding or collected by whey drying companies. At times, however, whey cannot readily be removed from the plant and is discharged to the sewer. The high strength of the whey may result in damage to the irrigated area by injuring or killing the cover crop, and by loading the soil too heavily with organic matter. Sanitary wastes from toilets etc. are commonly segregated from the milk waste and sent to a septic tank system for treatment. This segregation is considered advisable from a health standpoint since it prevents potentially dangerous organisms from being sprayed on the cover crop.

The milk wastes conducted by the plant sewers usually flow by gravity to the screen, which is generally located in the upper portion in the wet well. The concentration of suspended solids in milk wastes is usually low; however, it is always advisable to pass the waste through a basket screen or other screening mechanism to prevent clogging of pumps, samplers, and sprinklers and to reduce the possibility of scum or sludge formations which frequently result in the production of odors. Basket screens of stainless steel are most suitable but ordinary 1/8 to 1/4 wire mesh is often used satisfactorily. Screenings are best disposed of by burial at frequent intervals. A basket screen used at Plant D is shown in Figure 19.

The wet well or pump is usually constructed of concrete, and frequently is an existing septic tank converted for wet well use. This unit receives the waste from the plant sewer via the screen and retains it for a short period of time until pumped to the distribution field. For summer operation the wet well should be of sufficient size to hold the waste from approximately one hour of normal plant operation. Such a size results in frequent pumping, thus septic conditions and precipitation of milk solids seldom occur and odors are minimized. The geometry of the wet well is also important; a hopper bottom is most desirable as it permits the wet well to be pumped practically dry during each pumping cycle. The small amount of waste remaining at the end of each cycle may become septic but usually does not produce appreciable odors. In extremely hot weather it is advisable to provide facilities for flushing the wet well frequently with fresh water in order to remove septic, sour waste which may act as an inoculum causing fresh waste to deteriorate rapidly.

Winter operations in northern areas is best accomplished with the use of a large wet well, sufficient to hold a full day's waste. To reduce the possibility of freezing of the irrigation pipes and sprinklers the pump is usually started and stopped manually, thus once a day operation greatly reduces the time and effort required. In extremely cold weather the lines and sprinklers must be checked as soon as the pump starts since any clogging of a line or sprinkler quickly results in a frozen and ruptured unit.

It is desirable to so design the wet well that the lower and smaller portion may be used for summer operation and the entire well used for winter operation, thus eliminating the need for two units.

Pumping equipment may vary considerably; however electrically driven pumps are used almost exclusively as they readily permit automatic operation of the irrigation system. In some large installations in isolated areas gasoline driven pumps have been satisfactory even though manual operation was required.

Pumps are usually located in a dry well at such an elevation that no problem of priming occurs. There are, however, some installations in which the pump is placed directly over the wet well, or even in the wet well. Such installations frequently experience difficulties in loss of prime, corrosion of pumping equipment, and electrical shortages because of moisture.

Pumps are normally controlled by float switches, so adjusted that pumping starts as the wet well nears capacity, or at other desired levels. The shut-off position of the float should permit essentially complete emptying of the wet well. At some installations time controls for the pumps have been used, but in general these have not been as satisfactory as float type controls. Manual control of the pumps is frequently used where a minimum in cost of equipment is required. The latter method of control is not recommended since the wet well may overflow occassionally unless carefully watched. For winter operation in northern climates manual control of the pumps is usually necessary, as previously noted.

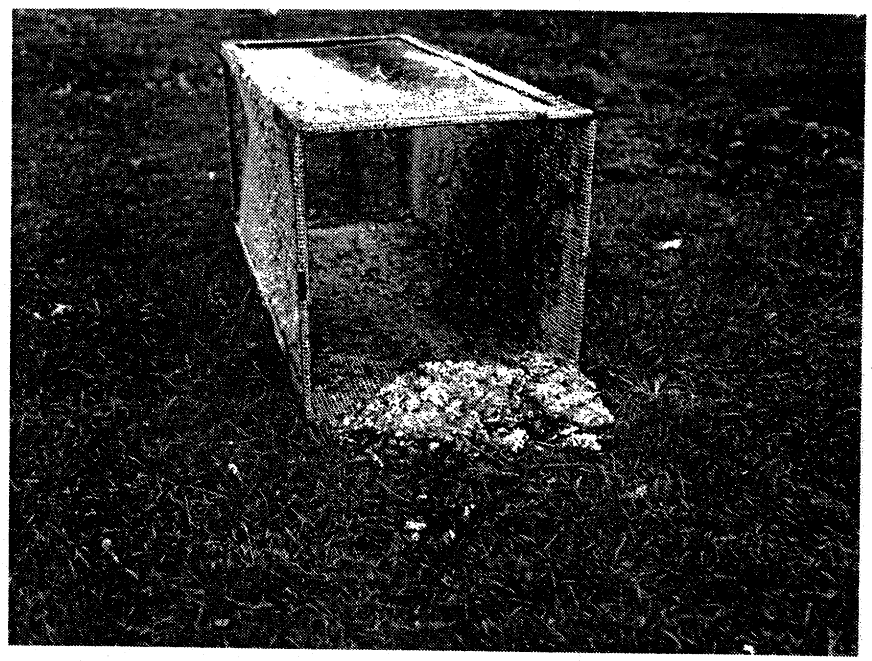


Figure 19 Basket Screen Used at Plant D

In nearly all spray irrigation installations there are no provisions for prolonged storage of the waste, thus auxiliary pumping equipment must be available for use in cases of failure of regular equipment. Failure to provide auxiliary pumps may result in flooding of low areas near the dairy plant, with resulting odors and fly problems in summer, and dangerously slippery areas in winter.

Where the irrigated area is at a higher elevation than the wet well a check valve is usually installed at the discharge side of the pump, so the waste in the whole distribution system will not drain back into the well when the pump is stopped. This check valve installation is satisfactory for summer operation but must be removed during the winter to allow drainage of the system to prevent freezing of the pipes.

In northern climates it is necessary to provide insulated shelter for the pumps for winter protection. In some cases heating facilities are provided to prevent freezing and to reduce the humidity which otherwise may cause corrosion of equipment. The interior of a typical shelter is shown in Figure 20.

Various materials have been successfully used for pipes in spray irrigation systems. For the permanent main line from pump to irrigation field steel pipe is most commonly used since it is strong, reasonable in cost, and readily available in a variety of sizes. Regardless of the type of material used the line should be laid so it will drain completely for winter operation. The size of pipe used should be able to carry the maximum capacity of the pump with reasonably low head loss.

Aluminum pipe is frequently used, but the cost and possibility of corrosion by alkaline wastes are factors that should be considered when making the selection. Plastic pipe has also been used, but failures have been reported (7, 18) especially when conveying warm or hot wastes. In one installation cement asbestos pipe (sewage type) was used, but it ruptured under pressure and was replaced by metal pipe. In another installation aluminum pipe corroded and was replaced by copper which was not appreciably affected by the alkaline wastes.

In the distribution system light weight aluminum pipes are usually used since they can be handled and moved readily by a single operator. In most installations the pipes and sprinklers are moved frequently, often several times daily, thus easily handled pipes are highly desirable. The frequency of moving depends on various factors, but the volume of waste applied, and the permeability of the soil usually control the cycle of application. In general, ponding is undesirable because of odor development and grass kills. The distribution system should be moved frequently enough so that these conditions do not occur.

Various types of joints have been used in irrigation systems. For the main line tight joints are usually used; however, when complete drainage cannot be accomplished in winter operation, self draining joints may be necessary. These self draining joints are essentially non-leaking under pressure but drain at each joint when pump operation ceases. These joints allow the pipes to be drained completely after each pumping cycle, thus greatly decreasing the possibility of freezing during winter operation. As a result of the drainage, however, ponding frequently occurs with its associated odors and grass kills during the summer. In the distribution lines self draining joints usually are satisfactory since the pipes are moved frequently and the short time ponding that develops at any one joint seldom produces critical conditions. Self draining joints in the distribution lines have the advantage of being connected or disconnected readily when the pipes are moved from one area to another.

Sprinklers are available in a variety of sizes from several manufacturers. Dealers specifications and recommendations are especially useful in making selections as to size and type. The number of sprinklers required will depend on the volume of waste, size of sprinkler nozzles, and the pressure developed by the pump. Capacities of the sprinklers usually range from about 10 gpm to above 50 gpm, and the operating pressures from about 25 psi to 100 psi. Apacing of the sprinklers also varies widely but 30 to 100 feet intervals are frequently used. Usually it is desired to cover an area completely and uniformly, thus the spacing should be such that all areas are covered, but with little overlapping.

For normal operation the sprinklers are mounted on, and just above, the distribution pipe, but for winter operation it is necessary to elevate the sprinklers to allow for the ice sheet that commonly forms. Risers from the distribution pipe or special tripods to hold the nozzles have been used satisfactorily. The latter type of support is more stable but because of its weight is more difficult to move. In other installations both the pipe and sprinklers are elevated and supported on posts. The ice sheet may develop to as much as two feet in depth, thus the sprinklers are frequently elevated to approximately 30 inches. When irrigating certain crops such as corn or tall grasses it may be necessary to elevate the sprinklers in order to obtain good distribution and coverage.

The nozzle openings should be large enough so that they do not clog readily. They usually vary from slightly less than ¼ inch to ¾ inch in diameter. The larger size nozzles are ordinarily indicated for winter operation since a clogged nozzle quickly becomes a frozen nozzle at low temperatures.

The actual costs of spray irrigation systems show extremely wide variations because of variations in the type of equipment used, in labor costs, in land costs, in equipment originally available, and in the extent of "home construction" of the system. Ten installations in Wisconsin showed variations from $400 to $2400 exclusive of land costs. The land costs also showed extreme variations. In many instances the dairy plant owned land suitable for irrigation, thus no further outlay was required. At some plants it was possible to rent land for irrigation purposes for very nominal amounts, while at other plants rental was often impossible and selling prices frequently were several times the usual value of the land.

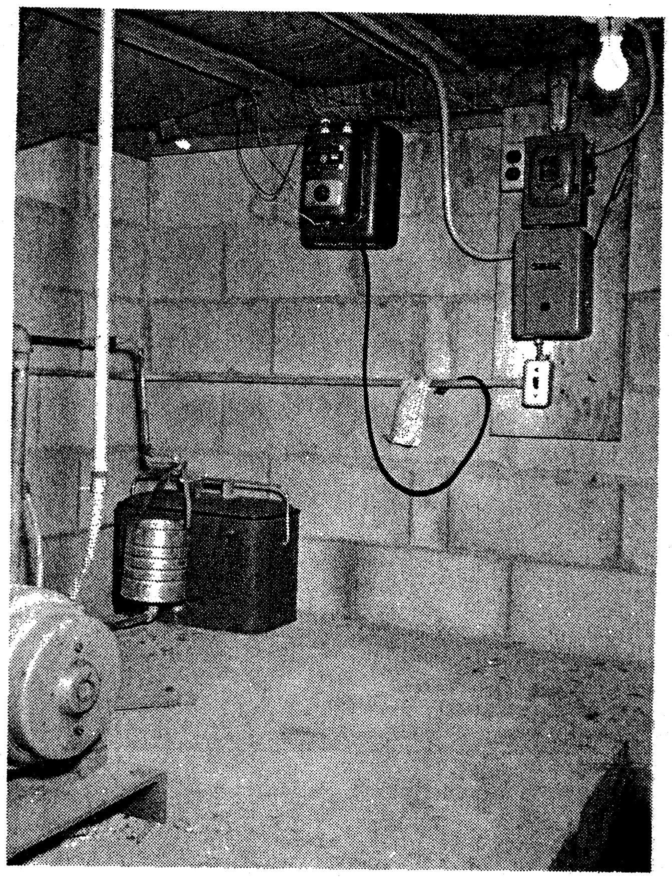


Figure 20 The Interior of a typical Pump Shelter

VIII. RESULTS AND DISCUSSION

General data relative to the milk plants and their waste systems are given in Table III. The milk intake at all plants is moderately low as is the volume of waste. At Plant E the waste volume is extremely low, apparently because of careful use of water, good housekeeping, and complete separation of whey from other wastes. The waste volumes are based on draw down-pumping data with the exception of those from Plant B where the record keeping by the operator was very erratic. At that plant the water meter readings were assumed to represent a close approximation of the waste volume.

The cost of the irrigation equipment varied widely, depending on the use of existing equipment and the amount of construction done by the owner. In general, however, the costs were moderate as compared to conventional types of treatment plants. Figures 21 and 22 illustrate a home devised sprinkler device in an exceptionally low cost irrigation system (plant E). A more conventional system is shown in Figure 23 at Plant B.

The extent of the irrigated areas showed wide variation from plant to plant. At Plant E there was considerable runoff to a cover area, hence the 0.018 acre is not truly representative. The application rate at this plant was roughly ten times that at the other plants, hence the runoff was not entirely unexpected.

Table III

Pertinent Irrigation Data

	Plant A	Plant B	Plant C	Plant D	Plant E
Milk Intake* (pounds per day)	20,500	20,000	33,500	10,600	13,500
Waste Volume* (gallons per day)	4,300	1,770	5,900	1,135	380
Cost of Irrigation System (Exclusive of land cost)	$837	$1,550	$2.300	$800	$400
Acres Irrigated					
1. Total	0.97	0.65	1.15	0.213	0.018
2. Each Setting	0.194	0.216	0.33	0.213	0.006
Pumping Rate* (gpm)	11	19.7	34	15.2	6
Pumping Duration* (minutes per day)	391	90	174	75	63
Application Rate* (inches per hour)	0.13	0.20	0.23	0.16	2.3
Main Line Pressure (psi)	20	23	95	14	3
Size & Length of Pipe	Al 1½" 280'	Al2" 260'	Galv 2½" 150' Al 2" 680'	Al 2" 280'	Galv 1" 100'
Type & Number of Nozzles	5 Skinner JU ¾	6 Rainbird JEE #20	10 Skinner JU ¾ LEE	5 JWW #20	flattened pipe nozzle
BOD Loading #/acre/day	322	295	139	212	675
Cover crop	alfalfa - brome hay	blue grass	blue grass, quack, brome	blue grass	blue grass & corn

*Average values

Analytical Control Characteristics

Analytical characteristics of the wastes usually associated with wastewater treatment control, Table IV, showed extreme variations between plants and within each plant depending on the time of sampling. High concentrations of organic matter were indicated by the values found for BOD, COD, and volatile residue. Undoubtedly the main source of this organic material was milk spillage and the dumping of whey into the wastewater. Good housekeeping and efficient operation of a milk plant can markedly reduce the strength of the wastes, as shown by the relatively low BOD and low volume of waste at Plant E. In contrast, the waste from Plant D had 3 times the volume and approximately 4 times the concentration of that from Plant E or about 12 times as much oxidizable matter from approximately the same milk intake.

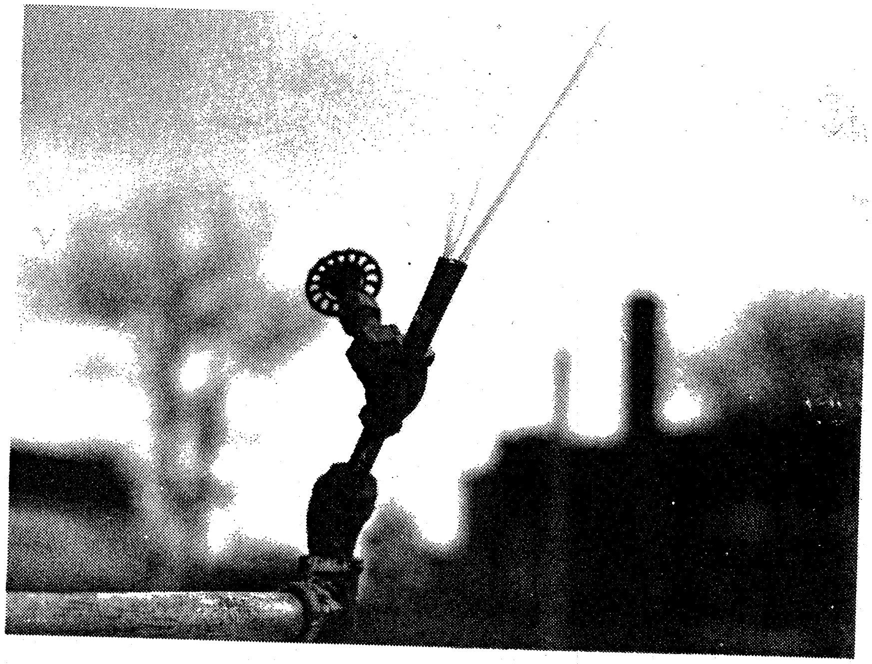


Figure 21 A Home devised Spray Nozzle

Figure 22 A Low Cost Irrigation System

Figure 23 A typical Spray Irrigation System elevated for Winter Operation (drainage of the pipe would be more certain if the pipe was also supported in the center of each section)

Table IV

AVERAGE AND RANGE OF SANITARY DATA
(Composite Samples)

	Plant A	Plant B	Plant C	Plant D	Plant E
B.O.D.*	1752 860-4740	4310 1980-9100	936 400-1620	4790 1849-9440	1280 435-2220
C.O.D.*	–	7800 3740-15320	1241 366-1880	4520 1467-11500	1703 552-2830
Ammonia*	–	36 20-76	7 1-31	19 1-68	15 2-40
Organic* Nitrogen	40 31-55	144 88-222	36 9-80	151 92-251	43 17-70
Alkalinity*	–	81 0-272	249 0-389	359 0-582	505 0-1088
pH	–	4.8 4.2-5.7	6.4 4.1-8.7	5.6 4.0-7.2	6.8 4.6-9.5
Residue, Total*	–	6490 3540-11990	2653 1000-8610	5450 3296-11434	2280 1208-3326
Residue, Volatile*	–	4740 2444-9988	1240 365-3720	3800 749-9404	1350 554-2346
Suspended Solids* Total	–	1040 600-1940	619 220-1980	1025 510-1800	361 273-502
Suspended Solids* Volatile	–	910 500-1840	561 220-1720	998 488-1540	303 200-390

*Values are given in parts per million
Upper values = average
Lower values = range

The pH and alkalinity values similarly showed wide variations, indicating differences in the freshness of the wastes as they are applied to the soil. The average pH values were rather low for all wastes, but at Plant D the values were consistently low, unboubtedly because of the presence of appreciable lactic acid, indicating that active bacterial decomposition was regularly taking place in the holding tank before the wastes were applied to the soil. Such a condition is conducive to the development of odors at the irrigation site. Odors at Plant D were more common than at the other plants. In general, the low pH values were encountered during the summer when biological activity was more rapid.

The suspended solids content of the wastes was relatively high and rather variable. All plants were equipped with screening devices for removing large particles from the waste, but the fines remained in the liquid which was sprayed. This leads to the proposed possibility that excessive amounts of these solids would tend to decrease the permeability of the soil and might lead to the development of odors. Good screening operations are essential to prevent clogging of the spray nozzles. The wastes having high BOD values also showed high suspended solids content, indicating deficiencies in the operation of the dairy plant itself. Suspended solids at all plants were in excess of 83 per cent volatile matter indicating the loss of milk products in the form of cheese curd and various solids formed during decomposition in the waste holding tank.

Elemental Composition of the Wastewater

The chemical composition of milk plant wastes is extremely variable (Table V) and was found to vary not only with the time of sampling during a given day but also from day to day. These data emphasize the fact that grab samples have relatively little value for waste composition determinations. The nitrogen, phosphorus, and potassium content of the wastewaters is much higher than those usually found in municipal sewage. It is believed that the major source of these elements is from the milk spilled or lost during processing, since no other major source of nitrogen or potassium was observed. If this is true, then the average nitrogen and potassium content of the waste from a given plant is a fairly reliable check on the amount of milk lost during processing. From the analyses it is evident that there is wide variation between plants in this respect.

The high phosphorus content results in part from the cleaning compounds used in the plants. Many of these compounds are high in phosphorus. Here again, the variability in the average phosphorus content of the wastes from the different plants is striking. This may be a reflection of the differences in kind and quantity of the cleaning compounds used and the amount of milk spilled. Because the water probably would be the major source of the calcium and magnesium, much less variability was found in the average values of these cations in the wastes from the different plants.

Table V

Average and Range in Cation and Anion Content of Wastes in ppm

Location	Nitrogen		Phosphorus		Potash		Sodium		Calcium		Magnesium		Chloride	
	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range	Ave.	Range
Plant A	–	–	17.1	6.5-27	57.8	26-118	166	103-216	76	46-92	49.6	32-60	180	128-278
Plant B	180	108-298	59.7	24-105	160.4	54-388	433	98-675	78.6	47-105	34.9	13-60	494	160-943
Plant C	43	10-111	31	12-77	37	4-62	470	183-796	66	44-94	37	24-60	559	186-1000
Plant D	170	93-319	132.3	33-194	137.6	31-452	374	282-642	76	43-101	40.6	20-140	264	104-710
Plant E	58	19-110	35.2	16-62	46.6	16-147	255	168-329	57.9	32-107	35.7	19-49	162	57-354

With the exception of sodium, the concentrations of the nitrogen, phosphorus, and other elements found in the wastes present no problem from the standpoint of spray irrigation. In fact, they can contribute markedly to the nutritional requirements of the crop being irrigated, as was evident at two sites (D and E).

The potential dangers of excessive amounts of sodium in an irrigation medium, particularly where fine textured soils are concerned, are well known. Although this problem was anticipated, the high sodium content found in the wastes from the plants studied was not expected. The major source of sodium in the wastes is from the salt (NaCl) used in the plant. The wide variation in the sodium content of the wastes between plants would tend to indicate that with reasonable care the sodium content of the wastes could be greatly reduced. It is worthy of note that at one plant when the owner was absent for a few days, the sodium content of the waste more than doubled.

The deleterious effects of sodium in the wastewater on soil aggregation or structure are not only dependent on the amount of sodium applied but also on the amount of other cations present. From the many studies carried out on the quality of irrigation water in relation to its use on western soils, the following formula (40) has been used for determining the suitability of the water:

$$\text{Percentage Na} = \frac{\text{Na} \times 100}{\text{Ca+Mg+Na+K}}$$

where cations are in gram equivalents per million. To be suitable for irrigation of western soils, the equivalent percentage of sodium should not exceed 80, not should the total concentration of cations, in equivalents per million, exceed 25. The percentage of sodium in the wastes included in this study ranged from 63 for Plant D to 44 for Plant C, thus indicating that they would be safe from this standpoint. Wastes from three of the plants, however, had total concentrations of cations which exceed the recommended permissible limit. The average total cation equivalents per million in the waste from Plants D, E, and C were 29.8, 27.0, and 28.3 respectively. Wastes from the other two plants averaged well below the recommended permissible limit with respect to the total cations. It is believed that in the more humid regions a fairly high salt concentration in itself does not constitute a serious problem because of the greater amount of leaching in the soils of these regions.

Soil Analyses

The analyses of soil samples taken the second year of irrigation are presented in Table VI. These tests indicate that a substantial increase in all ions has occurred in the soil, particularly in the 0-to-6 in. layer. On the soils that were low in available phosphorus and exchangeable potassium, the grass crop exhibited a marked improvement resulting from these nutrients in the wastewater.

Exchangeable calcium and magnesium contents are not presented because even though large additions were being made via the waste, the changes in the soil calcium and magnesium contents were relatively minor. Large amounts of these ions are normally present (on the order of several thousand pounds of calcium and 599 lb of magnesium per acre-half foot). However, the importance of the calcium and magnesium in the waste in counteracting the deleterious effect of sodium on the soil should not be minimized, as explained later. As expected, sodium and chlorides exhibit the greatest increase in the soil. Chlorides and sodium are normally low in soils of the humid region unless recently fertilized or heavily pastured. In the latter case large amounts of NaCl are added to the soil via animal droppings. This probably accounts for the relatively high sodium content of the unirrigated soil at site D. The relatively high chloride content of the unirrigated soil at side E is believed to be the result of lateral movement, since the chloride ion readily moves with the soil water. Several more years of irrigation will be needed to determine whether soil sodium content will reach harmful levels or whether equilibrium will occur before this happens. From the studies on quality of irrigation water in western states, it appears that the sodium is not present in the wastes in harmful amounts.

Table VI

Influence of Milk Plant Wastes on Acid Soluble Phosphorus, Water Soluble Chlorides, and Exchangeable Bases in the Soil.

Soil depth Inches	ppm Acid Sol. P.		ppm Water Sol. Cl		K		Na	
	I	U	I	U	I	U	I	U
			Plant A					
0 - 6	42.0	23.3	52.0	8.0	186	164	127	20
6 - 12	28.1	7.0	25.0	8.0	157	160	67	25
12 - 18	28.8	10.4	24.0	10.0	165	119	46	24
*18 - 24	36.6	7.6	28.0	8.0	*310	180	44	34
*24 - 30	62.0	27.4	20.0	6.0	*290	205	41	33
*30 - 26	75.0	55.8	16.0	8.0	*300	193	41	36
*36 - 42	103.0	69.4	16.0	8.0	*233	175	39	33
*42 - 48	124.0	72.0	8.0	8.0	*200	183	38	37
			Plant B					
0 - 6	72.9	37.4	390	12.0	168	72	447	26
6 - 12	56.7	37.2	280	11.0	72	51	268	23
12 - 18	54.1	35.8	295	22.0	53	48	185	23
18 - 24	39.8	33.9	231	16.0	50	62	104	27
24 - 30	39.8	44.0	214	17.0	62	62	108	22
30 - 36	37.9	45.0	181	19.0	54	85	92	27
36 - 42	64.3	44.3	230	20.0	62	97	118	29
42 - 48	47.7	44.8	215	21.0	63	92	110	27
			Plant C					
0 - 6	43.0	15.3	52.0	12.0	111	94	143	30
6 - 12	10.8	21.2	32.0	8.0	72	58	217	13
12 - 18	13.0	22.4	72.0	19.0	53	60	178	12
18 - 24	17.0	23.2	80.0	22.0	64	127	106	19
24 - 30	20.2	22.0	55.0	28.0	53	95	109	16
			Plant D					
0 - 6	96.7	62.3	83.0	48.0	250	90	213	128
6 - 12	51.7	51.3	59.0	27.0	134	70	52	93
12 - 18	57.3	51.0	48.0	20.0	174	95	56	55
18 - 24	58.8	51.0	44.0	22.0	182	106	53	40
			Plant E					
0 - 6	68.8	46.7	28.0	6.0	347	265	152	22
6 - 12	61.1	28.4	30.0	24.0	222	118	109	29
12 - 18	28.9	15.6	42.0	33.0	179	156	118	27
18 - 24	22.7	13.8	36.0	36.0	178	165	106	58
24 - 30	19.0	30.7	28.0	40.0	180	192	110	74

*Till or rock encountered in one of the excavations, therefore starred valued represent only one profile.
I – irrigated; U – unirrigated.

Soil Tests with Sodium

The harmful effects of sodium on the physical conditions of the soil are shown in Figures 24 and 25. The differential treatments for the soils in Figure 24 were as follows:

Sample A – leached with 500 ml of distilled water
Sample B – leached with 500 ml of city water which contains 70 mg/1 Ca and 53 mg/1 Mg, to which 1000 mg/1 Na had been added.
Sample C – leached with 500 ml distilled water containing 1000 mg/1 Na.

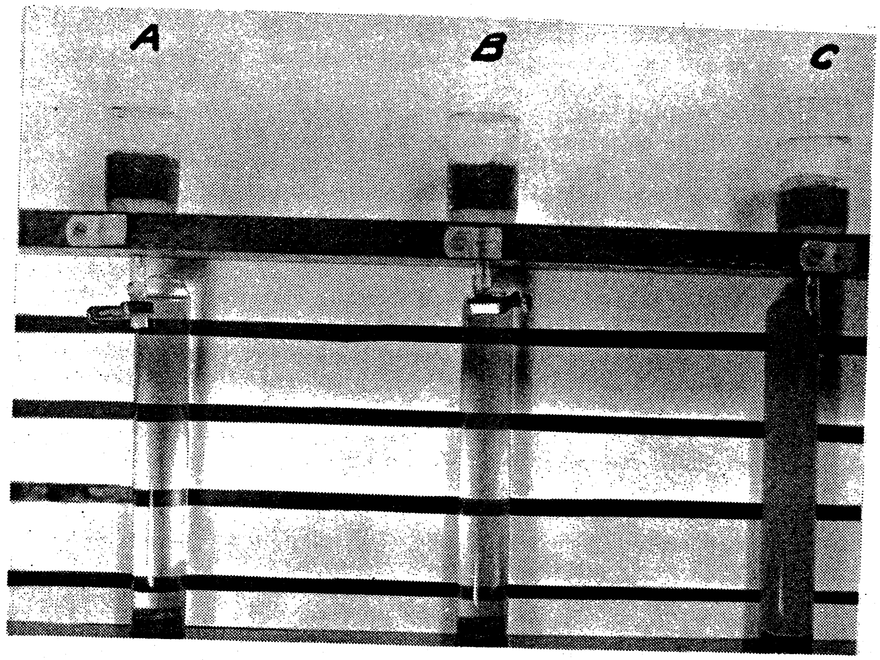


Figure 24 Test Apparatus showing Soil Structure as affected by Sodium in the Irrigation water when in the presence of Calcium and Magnesium

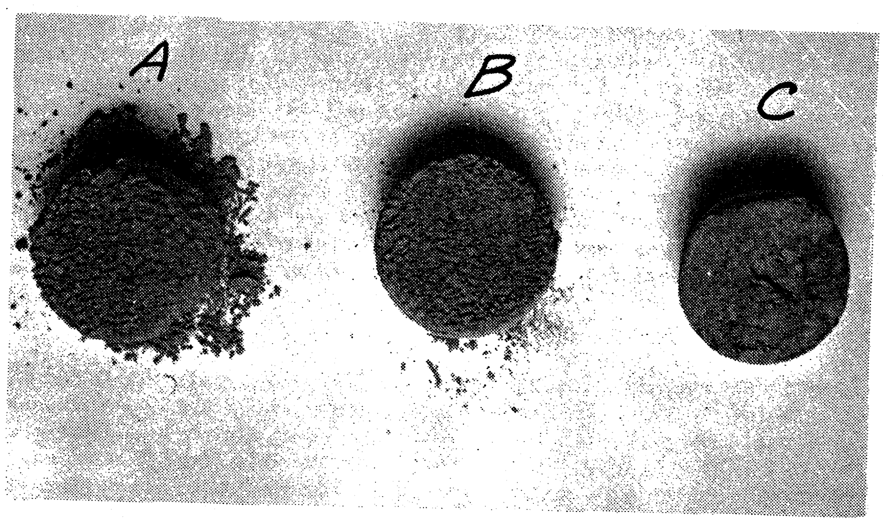


Figure 25 Soil Structure as affected by different concentrations of Sodium in the presence of Calcium and Magnesium

The three samples of soil in Figure 25 were treated as follows:

Sample A – leached with 500 ml of city water to which 2000 mg/1 of Na had been added.
Sample B – leached with 500 ml of city water to which 2500 mg/1 of Na had been added.
Sample C – leached with 500 ml of city water to which 3000 mg/1 of Na had been added.

In all cases the Na was added as Na Cl.

After the differential treatments had been made, all samples (in both studies) were leached with 500 ml of distilled water except for the C samples. In these cases the samples became virtually impervious after 250 ml of water had passed through. The soil structural breakdown in these tests is evident not only in the appearance of the soil (more easily seen in Figure 25) but also in the turbidity of the leachate (Figure 24). The turbidity is the result of dispersed soil particles passing through the cotton filter. The soil in the middle funnel exhibits only slight turbidity of the leachate. The beneficial effect of calcium and magnesium in irrigation water containing sodium can be explained as follows.

Soil clays, because of their negative charge, hold a large amount of cations in exchangeable form. When sodium constitutes about 15 per cent of the total exchangeable cations, the soil clays begin to disperse, and dispersion increases with an increase in sodium content. When the soil is irrigated with water containing only the sodium cation, replacement of the other cations occurs until a high percentage of the exchangeable cations is sodium. Depending on the sodium content of the irrigation water, it may be many years before before any noticeable deterioration of soil structure occurs. Also if sodium chloride or sulfate is present in the soil solution, it serves as a strong electrolyte and no dispersion occurs until it has been leached out by rains. Once the sulfates or chlorides have been leached, dispersion is very rapid if the soil clays contain a high percentage of sodium. Calcium and/or magnesium are more tightly bonded to clay than is sodium. Hence the presence of relatively small amounts of these cations in the irrigation water will have a marked depressing effect on the adsorption of sodium by the clay. Also, if the calcium and magnesium are present as the chlorides or sulfates, any sodium in the soil water remains in the chloride or sulfate form until leached from the soil. For example, in the laboratory test shown in Figure 24, the soil leached with city water containing 1,000 mg/1 sodium contained less than a third as much exchangeable sodium as the soil irrigated with water containing the same amount of sodium but no other cations (NaCl in distilled water). Soils that receive large additions of sodium, but only small amounts of calcium and magnesium, via the irrigation route, are benefited by applications of calcium sulfate at a rate of two or more tons per acre every few years.

Irrigation rates

When estimating land needs for the disposal of wastes by crop irrigation, the dairy plant operator is interested in the average daily amount of waste that can be applied to a given area. Obviously, there are no nard and fast rules that can be applied by all dairy plant operators for predicting loading rates, because these rates will vary from site to site with variations of kind of soil and underlying strata, nearness to the water table, and climatic conditions. With the plants under study, variations between fields in safe loading rates were quite striking. At Plant B the soil was sandy in texture and the water table was at a depth of about five feet. There were no dense clay layers in the profile. Consequently, when the irrigation line was left in the same position for a two-month period during the summer of 1956, no ponding or damage to the crop resulted. In contrast, at Plant D where the field under irrigation was silt loam overlying a fairly tight clay, runoff occurred almost every day shortly after irrigation was begun. However, because the irrigated portion of the field was at the head of a long draw, no pending, and consequently no damage to the vegetation, resulted. It should be pointed out that because of a similar situation the area actually used for disposal at site E was much larger than the specific area covered by the sprinklers (.006 acre).

The objectionable results of over-irrigation are evident in Figure 26. This site is not one that was under measurement, but is one of the sites included in a more general study of a larger number of existing irrigation disposal systems. The soil is a silt loam overlying a very slowly permeable clay at a depth of two feet below the surface. Since the topography is level, objectionable ponding resulted. This field had been seeded a short time before the date of this photograph and outside of the irrigated area the vegetation was beginning to cover the soil. However, in the irrigated and ponded areas, the vegetation was completely killed. It is evident that, when soils and topographical conditions such as shown in Figure 26 exist, irrigation or loading rates will be largely governed by transpiration and evaporation (about 0.2 in./day during the growing season in the Wisconsin area).

Although some plants are better adapted than others to a restricted soil-oxygen supply, no plant will live long when the soil is water-logged with media containing as much organic material as those encountered in this study.

There are strong indications that over-irrigation can cause an additional objectionable problem, namely, that of soil clogging. Recently it was called to the attention of these investigators that at one site (not included in this study) almost no waste waters appeared to be entering the soil but rather it was virtually

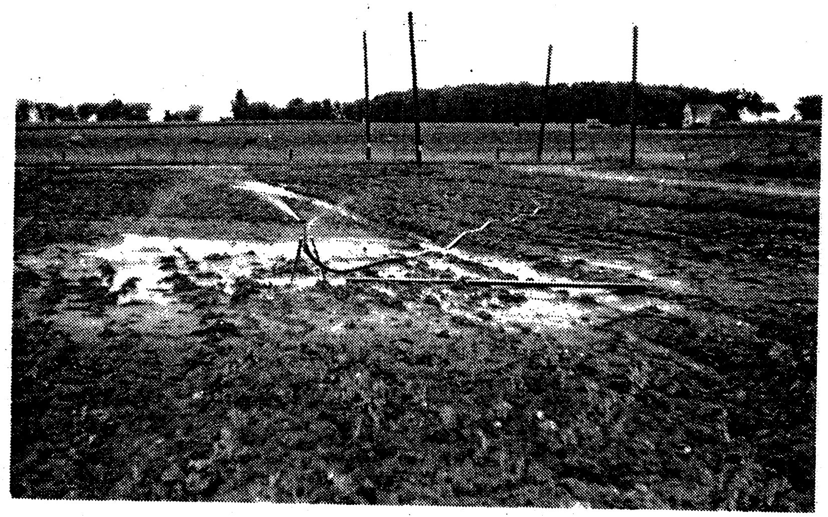


Figure 26 Waste disposal showing unsatisfactory management on poorly drained soil.

all running off. This field, which had a silty clay loam soil, had been under irrigation for several years before the problem became acute. Examination of the irrigated and unirrigated soil strongly suggests the cause was over-irrigation as was evident by the higher organic matter content and noticeable reduction of the iron in the irrigated soil. The unirrigated soil had an organic matter content of 1.8%, whereas in the irrigated soil it was 2.9%. This build-up in organic matter content was undoubtedly the result of poor aeration due to over irrigation. Similar effects of soil clogging have been noted in ground-water recharge studies even though the stream water used was low in BOD. Here again the evidence pointed toward a clogging of the soil pores by bacteria, slime molds, and other growths as a result of lack of aeration. By restoring proper aeration through carefully controlled irrigation these organic materials will oxidize with time so that the permeability of the soil can be restored.

On the other hand, large amounts of easily oxidizable materials which occur in wastes constitute no serious problem when the irrigation system is well managed. Thus, it appears desirable to observe the crop under irrigation to make a final evaluation of design application rates. The health of the crop is one good criterion to use in judging whether excessive application rates have been used.

Winter Irrigation

Year-round irrigation was carried on at three of the plants under study. During the winter months this resulted in an ice sheet of about 18 in. around the sprinklers. In all cases the irrigation pipe had been raised off the ground two feet or more. Special precautions for pipe drainage were necessary to avoid damage to the irrigation system. The plant operators found that, because of the inherent dangers to the irrigation system, manual operation during the winter months was almost a necessity. Much more attention, therefore, was required during the winter operation.

In the spring before ground temperatures were above freezing, the thawing ice sheet caused runoff. No objectionable odors resulted because the air temperature remained relatively low during the period of thawing By the time air temperatures were high the ice sheet had disappeared.

In all cases the original vegetation (mostly quack and blue grass) was slow in recovering or was killed out completely in the area covered by ice. At site B, a level field, the grasses never did return and it was necessary to reseed the area killed. At site C the crop was slow to recover (note enclosed area, Figure 27), but by July there was no difference between the area covered by ice and the uncovered areas (Figure 28). The latter site differed from site B in that it was on a fairly steep slope, and this may be the explanation for the differences encountered. It is likely that, where winter disposal by means of irrigation is being followed, the plant operator may have to plan on re-establishment of the crop the following spring on the winter-irrigated area.

Other Plants Studied

Because of the limited number of dairy plants included in this study it was believed that additional valuable information could be obtained by making observations at a relatively large number of sites where waste disposal by means of irrigation had been carried on for some time. Therefore, in August, 1957, 17 milk plants in central and western Wisconsin were visited to study the problem encountered in waste disposal by means of spray irrigation and ridge and furrow irrigation systems. The daily milk intake, waste volumes, information concerning the disposal systems, types of soil being irrigated, and other pertinent data were studied.

The study indicated that during the summer either spray irrigation or ridge and furrow irrigation offers a satisfactory method of milk waste disposal in this region, provided the irrigation site was well designed, constructed, and operated. It appeared that for winter use the ridge and furrow system was the more satisfactory, but for summer use a well designed spray system may be more economical. Some dairy plants using spray irrigation are considering a ridge and furrow system for winter usage. Such a combinations is necessarily more expensive but may prove to be most satisfactory in the long run.

Those plants using spray irrigation had various methods of winter disposal, such as: 1) use of septic tanks and dry well, 2) direct discharge to a stream, 3) discharge to a roadside ditch, 4) spray irrigation, and 5) lagooning. Certain plants segregated their strong waste from the cooling water, and simplified the disposal problem in winter by discharging the cooling waters into a ditch or stream.

In general the spray irrigation systems have not proven completely satisfactory for winter use in this climate, because as mentioned earlier, the ice layer killed the vegetation. Also, unless the system was properly designed, damage to the irrigation equipment resulted from freezing.

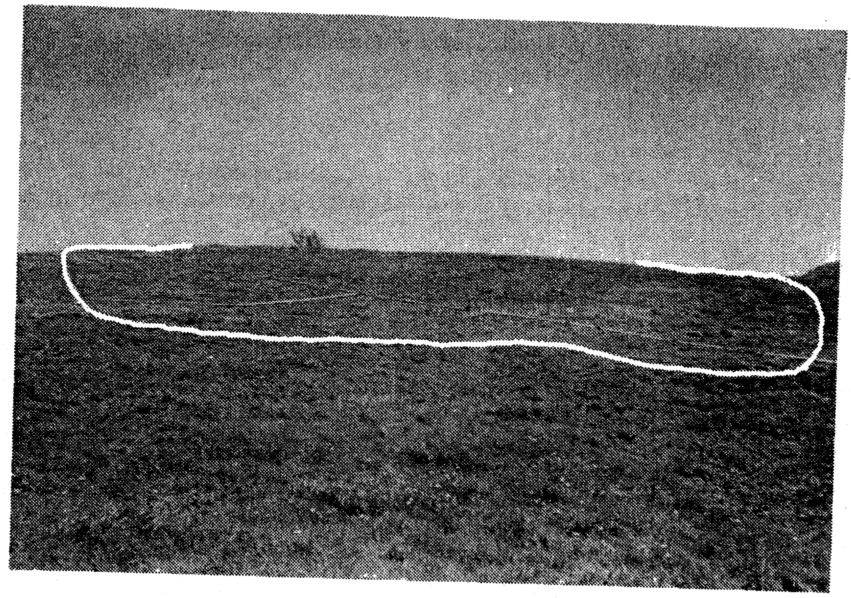


Figure 27 Crop injury resulting from ice sheet formed during winter irrigation. (Note the top portion of the slope.)

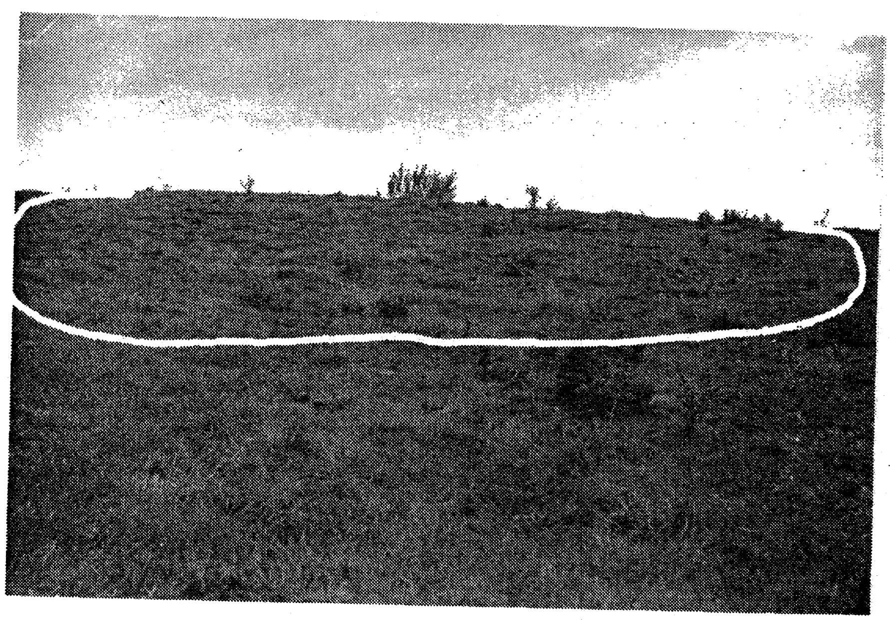


Figure 28 Recovery of grass crop by July following the winter irrigation. (Note the top portion of the slope.)

Of the plants visited, only a few were considered to be operating entirely unsatisfactorily and accomplishing insufficient treatment. One plant was noted to have some runoff from the field to the stream, and another to a roadside ditch. One area had a definitely objectionable odor and several others had moderate odors but probably not serious enough to result in complaints. A few systems had leaks in pipe joints that caused local ponding. This problem could be remedied readily. One plant was discharging waste directly to the stream because of ponding in the field, but methods were being considered to improve the situation.

Waste water disposal appeared to be greatly enchanced by good growths of vegetation in either type of system. Deep rooted grasses, such as Reed's canary grass, appeared to be most satisfactory. In some areas considerable difficulty has been experienced in obtaining good growths of grasses.

Several of the wet wells in use were considered to be too large, causing infrequent pumping and large volume applications to the irrigated area in a short period of time. This resulted in some ponding accompanied by damaged vegetation and objectionable odors. In addition, wastes stored too long in the wet well developed strong odors (as a result a septic conditions) which were very noticable when the sprinkler system was in operation.

Ponding in irrigation fields also occurred frequently when the sprinklers remained in one area for too long a period. Unless the soils are sandy it appeared that the irrigation pipe should be moved daily, or at least every other day, when large amounts of waste are being applied. This is especially necessary when the soil has low permeability or there is a high water table.

Where high water tables were encountered, several plants placed tile lines at a depth of 2½ to 3 feet. In general the tile lines have improved the percolation of waste through the soil. The drainage waters leaving the tile line were generally low in BOD.

It was noted that disposal areas in creek bottoms tended to give trouble because of the high water table. Ponding often occurred in such areas, resulting in overflow into the creek. Under the conditions odors were prevalent and vegetation was killed or damaged.

Observations made at these 17 dairy plants again emphasizes the importance of careful selection of irrigation site, design of equipment, and proper irrigation management. Whenever possible, sites on well-drained soils well above a water table should be selected. Since many milk plants are located on stream bottoms, some extra initial cost may be involved in obtaining higher ground but if the land in the stream bottom has serious limitations and can not be adequately improved by tiling, the extra expense is justified.

Although tiling of the irrigated area has proved beneficial, at some sites it is known to be ineffective. It appeared that in some cases due consideration had not been given to the soil strata overlying the tile line. When a silt or fine sand layer containing little clay occurs, percolation through this layer may be so slow that tile placed below this layer is virtually useless. Vertical gravel columns placed at frequent intervals over the tile lines have proved to be effective in many drainage systems, and should be tried in some of those disposal areas where unfavorable soil conditions are encountered.

Figure 29 shows what can happen when a poor site is selected. This was a low lying field close to the milk plant. As is obvious, it has a high water table. It was pointless to put in a ridge and furrow irrigation system since the furrow bottoms are below the water table. There would be no more, if any, objectionable odors if the waste were allowed to pond on the surface and the plant had saved the cost of the ridge and furrow construction. It is possible that such a site as this could have been improved by tiling, but a careful study of the soil conditions and fluctuation of water levels in the nearby stream would be needed before a definite answer could be given.

Figure 30 illustrates a poorly designed sprinkler system. Since the sprinkler line is elevated and designed so that it can not be moved, the undesirable effects of over-irrigation are all too evident. The net result is that the system is little more effective than if the waste waters were run out on the ground and allowed to pond.

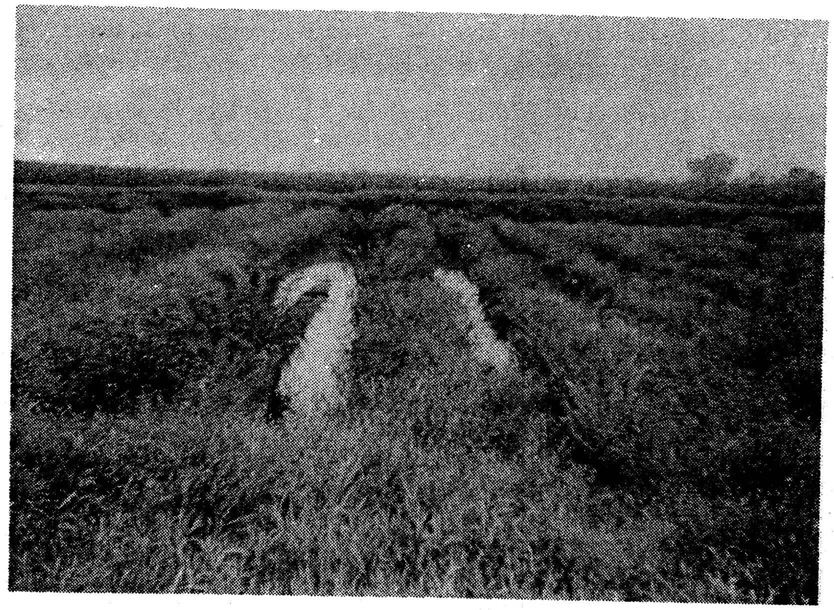


Figure 29 A ridge and furrow disposal system showing problems encountered with a high water table.

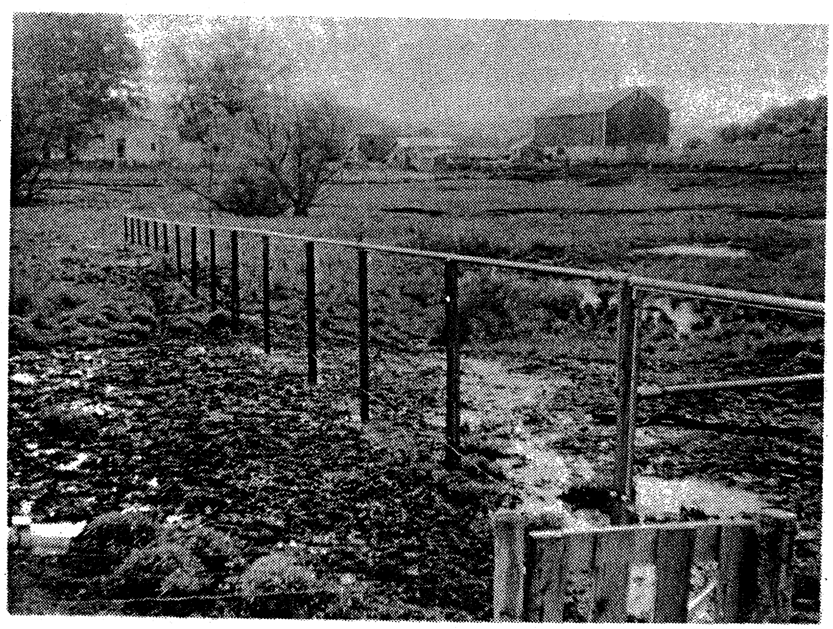


Figure 30 Irrigation field showing the objectionable effects of over-irrigation because of poor sprinkler system design.

1. Spray irrigation appears to be a practical, economical, and satisfactory method of disposal of dairy wastes when the area to be irrigated is properly selected and reasonable care is exercised in the operation of the system.

2. The volumetric loading and the cation loading appear to be the principal design factors when considering spray irrigation. The BOD loading is much less significant than it is in the design of biological treatment systems providing soil aeration is good at all times.

3. Reasonable predictions of loading or irrigation rates of a given site may be made when soil conditions, type of cover crop, depth of water table, and other pertinent information are known. However, final design application rates can best be determined by observance of the crop under irrigation.

4. The waste-holding tank should be designed so that it can be completely emptied during each pumping period. In the summer maximum detention time should not be over 1 to 2 hours, and the tank should be flushed frequently to remove accumulated solids which otherwise will cause objectionable odors.

5. From a mechanical standpoint, winter operation of spray irrigation systems is possible in areas comparable to the latitude of central Wisconsin, but it must be assumed that a complete kill of the cover crop will occur. However, the irrigation operation may be reasonably carried out by having alternate areas available in order that reseeding may be accomplished readily.

6. For winter operation the wet well should be capable of holding the maximum daily flow in order that only one pumping of waste is required per day. Manual starting of the pump should be practiced and the pipe and sprinklers observed until the whole system is operating normally.

7. Where the cover crop is to be cut, a week to 10 days is usually necessary to dry the field for cutting and baling for storage.

8. A small insulated shelter is necessary to protect the motor and pump, and to shelter the waste from heat and cold.

9. A screening unit is desirable. It is usually placed at the inlet of the wet well; maximum mesh size should be ¼ inch. Daily cleaning is important.

10. The nozzle size in sprinklers should be large enough so that clogging is minimized. For winter operation it may be advisable to increase nozzle size to prevent clogging.

11. Normally a back flow valve at the discharge side of the pump prevents the lines from draining back into the wet well after each pumping cycle. In winter, however, the lines must drain completely after each pumping cycle to prevent freezing.

12. It is desirable to locate the disposal site so that prevailing winds will blow odor and fine spray away from the cheese factory.

13. Waterproofing materials used on the interior of the wet well should be resistant ro the high temperatures of the discharged cooling water.

14. Ideally the flow line of the pump should not be above the lowest water level of the wet well in order to prevent loss of prime, otherwise a self priming pump is recommended.

15. To prevent corrosion of float switch and electrical contacts it is desirable to locate the float switch outside the wet well.

16. When the pump shelter is above the wet well a watertight cover should be placed over the wet well opening to reduce condensation thus protecting the insulation in the shelter, the motor, float switch and other equipment. A small electric heater may be necessary in some cases to reduce condensation in the shelter.

17. An evaluation of the effect of runoff from the ice cover during winter and from the spring thawing of the ice cover itself should be made at each site, based on the dilution available by the stream and on other factors peculiar to the site.

18. Hot wastes that are damaging to the cover crop may be successfully irrigated by elevating the spray nozzles, thus allowing the waste to cool as it falls.

19. In some irrigated areas having poor absorption characteristics, the use of tile systems several feet below the surface have greatly increased the flow of waste through the soil. The effluent from the tile system has been found to be low in BOD and relatively stable. There are some soils, however, that are difficult to drain. Therefore a qualified person should be consulted before drainage is undertaken.

20. In cold areas, serious consideration should be given to alternate methods of disposal during the winter period.

APPENDIX

SAMPLING PROCEDURES AND METHOD OF ANALYSES

The sampling procedure used for obtaining representative aliquots of the waste liquid were described earlier and therefore are not repeated here. A brief outline of chemical and sanitary methods of analyses of the waste waters and the soil sampling procedures as well as the chemical and physical methods used in the soils determinations follow.

SANITARY ANALYSES METHODS FOR WASTES

The procedures followed in the sanitary analysis of the milk wastes conformed to those given in the 10th edition of "Standard Methods for the Examination of Water, Sewage, and Industrial Waste" (32).

Biochemical oxygen demand. Calculated volumes of the fresh waste were pipetted in duplicate into standard BOD bottles which were then filled with standard Formula C dilution water, to which settled raw sewage had been added as seed. Dissolved oxygen determinations were made at once on one of the duplicates and the other incubated for 5 days at 20°C. After incubation the dissolved oxygen content was determined and the oxygen depletion calculated for each dilution. The BOD was computed, after making a seed correction, from the depletion and dilution factor for each bottle. The azide modification of the Winkler dissolved oxygen determination was used in measuring the oxygen content. Generally three dilutions, in duplicate, of each sample were made and the acceptable BOD values averaged for each waste.

Ammonia nitrogen. The ammonia content of the wastes was determined by a Kjeldahl distillation followed by Nesslerization of a measured portion of the distillate. After color development the optical density was measured in a Coleman Model 11 spectrophotometer at 410 Mu. The ammonia content was then determined from the standard working curve and the volume of sample used. All concentrations were computed in terms of mg N/liter.

Organic nitrogen. The residue from the ammonia distillate was digested with sulfuric acid and copper sulfate solution until a clear liquid obtained. After cooling, the digestate was diluted with ammonia free water, neutralized with sodium hydroxide and distilled into a boric acid solution. The organic nitrogen was then determined by titration with standardized sulfuric acid and computed as mg N/liter.

Chemical oxygen demand. 50 ml portions of the raw waste samples were thoroughly mixed with 25 ml N/4 potassium dichromate and 75 ml C.P. sulfuric acid in 500 ml round bottom standard taper flasks. The flasks were attached to condensers and refluxed for 2 hours. The mixtures were then cooled, diluted to about 300 ml and titrated with N/4 ferrous ammonium sulfate using O-Phenanthrolin as the indicator. The C.O.D. values were computed as mg. oxygen/liter.

pH measurements were made with Beckman electric pH meters, models H2 and N.

Residue. 50 ml samples in tared porcelain evaporating dishes were evaporated, dried at 105°C, cooled and weighed. The volatile residue was determined by igniting at 600°C for 15 minutes, cooling and again weighing.

Suspended solids. Waste samples were filtered through tared gooch cruicibles prepared with asbestos mats. They were dried at 105°C, cooled and weighed. Volatile matter was determined by igniting at 600°C for 15 minutes and again cooling and weighing.

Alkalinity. Waste samples were titrated with N/50 H_2SO4 using phenolphthalein and methly orange as indicators. Alkalinities were calculated as mg/liter as $CaCO_3$.

CHEMICAL ANALYSES METHODS FOR WASTES

Cations. Potassium, calcium, magnesium, sodium, chlorides, and phosphorus were determined in the waste waters as follows: An aliquot of fifty ml. was pipetted into a 100 ml. beaker and evaporated to dryness of a 95°C hot plate. The samples were then placed in a muffle furnace and ignited at 500°C for three hours. After the samples cooled, ten ml. of 8 N HCL was added and they were placed on the 95°C hot plate for twenty minutes to digest. After cooling the samples were filtered through Whatman No. 40 filter paper and diluted to 200 ml. with distilled water, giving a four fold dilution of the original sample and a normality of 0.4 with respect to HCL concentration (11). Calcium and magnesium were then determined with a Beckman Flame Spectrophotometer, Model DU, and potassium and sodium with a Perkin-Elmer Flame Photometer, Model 52c. A four fold dilution usually sufficed, however, if additional dilution was required 0.4 N HCL was utilized.

Phosphorus. For the determination of phosphorus, an appropriate amount of the above solution ranging from one to ten ml. was pipetted and transferred to a 50 ml. volumetric flask and brought to volume with 0.4 *N* HCL. This solution was then transferred to a 125 ml. erlenmeyer flask and color developed with the addition of twelve ml. of chloromolybodic acid reagent and 6 drops of chlorostannous reductant. After five minutes the color intensity was read by use of a Bausch and Lomb, Model No. 20 colorimeter using a 690 millimicron light filter (35,36).

Chlorides. Chlorides were determined on a 10 ml. aliquot of the raw effluent which was brought to 50 ml. in volume with distilled water and then titrated with 0.0282 *N* $AgNO_3$ using 0.5 ml. of saturated K_2CrO_4 solution as an indicator. Concentrations were such that one ml. of 0.0282 *N* $AgNO_3$ equaled one mg of chloride (22).

Determinations were carried out in duplicate and average values reported.

SOIL SAMPLING PROCEDURES

Soil samples were taken in six-inch increments to depths of 30 to 42 inches, the depth of sampling being dependent upon underlying strata such as glacial fill or bedrock.

Two composite samples for chemical analyses and soil particle size distribution were taken with a soil auger from both the irrigated and the unirrigated areas. Ten borings were made for each composite sample and the soil from the ten borings for any given six-inch layer was placed in a separate paper bag.

To obtain samples for bulk density determinations (1) excavations to the desired depth were made in four different areas of a field. Undisrupted soil cores were taken at the desired depth from the exposed profile with a seamless cylinder soil sampler. The sampler was designed to accommodate a 12 oz. seamless crown "spray-tainer" which had the bottom removed (A description of the sampling equipment is given by Tanner and Wengel (33).

CHEMICAL ANALYSES METHODS OF SOILS

The soils samples collected from the different disposal sites were analyzed for exchangeable Na, K, Ca, and Mg; for acid soluble P; water soluble Cl; and pH. A brief outline of the chemical method used in the above determinations follows.

pH. The soil was dried a 60°C and pulverized to pass a 20 mesh sieve. Soil pH was determined, using 1:1 soil-water ratio, with a glass electrode.

Chlorides. Chlorides were determined on a 50g soil sample using 50 ml. of a 2% $CaNO_3$ solution for the extractant. After 15 minutes of shaking the sample was filtered and the chlorides were determined on 25 ml. aliquot of the filtrate according to the procedure used for chloride determination in the waste water (see Chemical and Biological procedures of waste analyses).

Available Phosphorus. Weak acid soluble phosphorus was determined on a one-gram sample of soil according to the methods of Truog and Meyer (35, 36). The soil was added to 200 ml of 0.002 *N* H_2SO_4 buffered at pH3 with 3 gm. K_2SO_4/1, and shaken for 30 minutes. Phosphorus in the filtrate was determined as the ammonium Phospho-Molybdate complex by means of a Bausch and Lomb Model 20 colorimeter.

Exchangeable bases. Exchangeable Ca, Mg, Na, and K were extracted with 1*N* ammonium acetate adjusted to pH 7. Ten grams of soil were added to 100 ml of extracting solution and shaken for 30 minutes. The concentrations of Ca, Mg, Na and K in the filtrate were determined with the Model DU Beckman flame spectrophotometer equipped with a photomultiplier.

PHYSICAL MEASUREMENT METHOD OF SOILS

Particle size distribution. The percentage of sand, silt and clay (particle size distribution) in the soil samples were determined as follows: A 50 gram sample of 20 mesh oven dried soil was placed in a 1000 ml Florence flask. 100 ml of dispersing solution (45.7 gms of $(NaPO_3)_6$ and 1.82 gms of Na_2CO_3 brought up to one liter with distilled water) and 400 ml distilled water were added and the soil allowed to slake for twelve hours. The slurry was then transferred to a standard milk-shaker using distilled water to complete the transfer. After 15 minutes of mixing, the sample was transferred to 1000 ml graduate

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1) Bulk density is defined as grams per cubic centimeter of oven dry soil including the pore space. Since the density of the soil solids (exclusive of soils high in iron oxides) will average 2.65 g/cc the soil pore space is inversely related to the bulk density.

APPENDIX

Table 1. Textural Classification of the Soils being irrigated by the milk plants under investigation.

Soil Depth Inches	%Sand		%Silt		%Clay		Textural Class	
	I*	U*	I	U	I	U	I	U
Plant A								
0 -6	19	32	67	52	14	16	Silt loam	Silt loam
6 - 12	18	14	65	54	17	22	Silt loam	Silt loam
12 - 18	17	10	59	65	24	25	Silt loam	Silt loam
18 - 24	16	8	60	61	24	31	Silt loam	Silty clay loam
24 - 30	20	9	60	58	20	33	Silt loam	Silty clay loam
30 - 36	20	16	60	54	20	30	Silt loam	Silty clay loam
36 - 42	19	23	62	51	19	26	Silt loam	Silt loam
42 - 48	22	15	59	59	19	26	Silt loam	Silt loam
Plant B								
0 - 6	26		64		10		Silt loam	
6 - 12	28		64		8		Silt loam	
12 - 18	44		48		8		Loam	
18 - 24	51		44		5		Silt loam	
24 - 30	27		67		6		Sandy loam	
30 - 36	24		66		10		Sandy loam	
36 - 42	34		56		10		Silt loam	
42 - 48	29		60		11		Silt loam	
Plant C								
0 - 6	47	48	45	42	8	10	Loam	Loam
6 - 12	47	57	42	31	11	12	Loam	Sandy loam
12 - 18	64	73	27	14	9	13	Sandy loam	Sandy loam
18 - 24	72	80	20	9	8	11	Sandy loam	Sandy loam
24 - 30	88	76	4	13	8	11	Sand	Sandy loam
30 - 36	92	74	2	15	6	11	Sand	Sandy loam
36 - 42	93	88	1	4	6	8	Sand	Sand
Plant D								
0 - 6	41	25	51	55	8	20	Silt loam	Silt loam
6 - 12	37	27	63	50	26	23	Sandy loam	Silt loam
12 - 18	41	32	59	43	30	25	Sandy loam	Loam
18 - 24	47	36	53	42	39	22	Sandy loam	Loam
24 - 30	42	46	58	38	32	18	Sandy loam	Loam
Plant E								
0 - 6	14	16	72	70	14	14	Silt loam	Silty loam
6 - 12	12	12	72	66	16	22	Silt loam	Silty loam
12 - 18	13	15	67	57	20	28	Silt loam	Silty clay loam
18 - 24	10	12	62	60	28	28	Silty clay loam	Silty clay loam
24 - 30	12	16	56	56	32	28	Silty clay loam	Silty clay loam

*I-irrigated, U-unirrigated.

cylinder and brought to one liter volume with distilled water which had been allowed to equilibrate to room temperature. The cylinder was shaken end over end, using one hand as a stopper, until the suspension was homogenous throughout. The hydrometer (3) is inserted and two drops of amyl alcohol added so as to minimize the froth and facilitate reading the hydrometer.

Hydrometer readings were taken at one minute and at two hours, the former giving the grams of silt and clay and the latter the grams of clay per liter (temperature correction must first be made or all readings). The amount of the silt and sand in the sample are obtained by differences.

The textural classifications of the soils are given in the following table. These data are presented to indicate not only the type of information that can be obtained, but more important, the fairly high degree of variation that can be normally expected even when samples are taken from sites in relatively close proximity. This means that a much larger sampling is needed to give a better indication of the average conditions. Because of the limited number of fields in this investigation a more detailed study did not appear warranted. The differences in texture noted in a given field cannot be attributed to irrigation since this would have no effect on soil particle size.

Bulk density. The bulk density of the soil was determined by the Paraffin block method described by Shaw (30). The undisrupted soil core is oven dried and then waterproffed by immersing in melted Paraffin. The volume of the core can then be determined by the volume of water it will displace. This is most easily done by weighing the core in air and when immersed in water. The differences in weight is a direct measure of the core volume after the density of the water as affected by the temperature is taken into account. For a high degree of accuracy the density and weight of the paraffin on the core must also be considered.

Percentage pore space. The percentage pore space in a soil can be calculated once the bulk density is known. Since the average particle density of a mineral soil is 2.65 g/cc (except for soils high in iron or heavy minerals) the pore volume be calculated from the bulk density (D_b) as follows:

$$\% \text{ Pore space } = 100\% - \left(\frac{Db}{2.65 \text{ g/cc}} \right. \times 100$$

For a given type of soil, i.e., silt loam, clay loam, sand, etc., soil aeration is quite closely related to the per cent pore space, since the greater the pores space the greater will be the percentage of large pores. Pores only over a given diameter will drain under the force of gravity. It is important that a soil has a fairly good distribution of large pores if it is to remain well aerated during a rainy period or intensive irrigation. The permeability of fine textured soils (silty or clayey) is governed more by the pore size distribution through the profile than by the total pore space. It is worthy of note that sands, which normally have less pore space than silty or clayey soils, are usually better aerated than the finer texture soils because of the higher percentage of large pores.

The bulk densities and the percentage pore space in the different soils under irrigation are given in table 2 (appendix). The striking variation in the bulk densities and consequently the percentage pore space in a given field is most apparent. This means that a much larger sampling would be necessary to obtain a true average value. It should also be noted that at Plant E where the soil had the highest average pore space there was considerable mottling in the soil indicating poor aeration. Although pore size distribution was not determined it is likely that there were relatively few large pores since the soil varied from a silt loam to clay loam. There was also evidence of mottling in the irrigated soil at site A, the other field containing fine textured soil. This again emphasizes the fact that total pore space is not a reliable criteria of degree of aeration under irrigated conditions.

Pore size distribution. Although a knowledge of the pore size distribution might contribute valuable information to a study such as this, these studies were not made because of the limited number of soils under investigation, and because of the lack of a suitable bench mark as to what might constitute a poorly aerated soil under the irrigated condition. However, because information on soil aeration might provide valuable data in a more comprehensive study involving a larger group of soils a brief outline for measuring pore size distribution is given.

Pore size distribution is estimated from the moisture-release curves as follows: Undisrupted core samples are trimmed leaving 0.1" to 0.25" soil extending beyond the can. The bottom of each core is covered with two layers of cheese cloth held on the can by a rubber band. The cores are vacuum saturated and the wet weight of each core is determined (33). The cores are placed on a tension plate and tension adjusted to 10 cm water with reference to the center of the core. After 24 hours the cores are removed and weighed. The weight of each core then is determined at tensions of 20, 40, 60, and 80 cm of water. Equilibrium is tested by weighings on successive days.

After equilibrium at the highest tension is attained, the volume of the core is determined, the core is oven-dried and the over-dry weight determined. The oven-dry volume of the core is then measured as outlined earlier. Pore size distribution can then be calculated, as a ratio of the weight of the vacuum saturated core and the weight of the water removed at the specific tensions and then converted to a percentage.

APPENDIX

Table 2. Bulk Density and Porosity of the Soils Studied 1/

Soil Depth Inches	Bulk Density, g/cc				% Pore Space				Av. Bulk Density	Av. % Pore Space
	Site 1	Site 2	Site 3	Site 4	Site 1	Site 2	Site 3	Site 4		
					Plant B					
0 - 6	1.45	1.54	- -	1.56	45	42	- -	41	1.52	43
6 - 12	1.47	1.45	1.28	1.46	45	45	52	45	1.42	46
12 - 18	1.37	1.62	1.27	1.35	48	39	52	49	1.40	47
18 - 24	1.37	1.42	1.41	1.43	48	46	47	46	1.41	47
24 - 30	1.26	1.22	1.31	1.45	52	54	51	45	1.31	51
30 - 36	1.57	1.30	1.47	- -	41	51	45	- -	1.45	45
					Plant C					
0 - 6	1.53	1.52	1.48	1.33	42	43	44	50	1.47	45
6 - 12	1.50	- -	1.42	1.48	43	- -	46	44	1.47	45
12 - 18	1.43	1.43	1.44	1.50	46	46	46	43	1.45	45
18 - 24	1.40	1.46	1.45	1.55	47	45	45	42	1.43	46
24 - 30	1.45	1.45	1.64	1.58	45	45	38	40	1.53	42
					Plant D					
0 - 6	1.30	1.33	1.36	1.57	51	50	49	41	1.39	48
6 - 12	1.35	1.47	1.36	1.64	49	45	49	38	1.46	45
12 - 18	1.04	1.42	1.27	1.40	61	46	52	47	1.28	52
18 - 24	1.11	1.42	1.44	1.42	58	46	46	46	1.35	49
					Plant E					
0 - 6	1.45	1.26	1.38	1.23	45	53	48	54	1.33	50
6 - 12	1.27	- -	1.26	1.46	52	- -	53	45	1.33	50
12 - 18	1.21	1.25	1.40	- -	54	53	47	- -	1.29	49
18 - 24	1.16	1.38	1.34	1.34	56	48	49	49	1.31	49
24 - 30	1.46	1.35	1.39	1.41	45	49	48	47	1.40	47

1/ Sites 1 and 2 represent the irrigated, and sites 3 and 4 the unirrigated portions of the field. Since soil variation was far greater than treatment variation the results are presented so that soil variation is readily evident.

2/ Where there are missing values, a rock or root occurred in the sample. These samples were discarded.

APPENDIX

TABLE 3

Analytical Characteristics of Milk Wastes from Plant A [1]

1956	BOD	NH_3	TON	pH	Alk Tot	Alk HCO_3	COD	Solids Total Tot.	Solids Total Vol.	Solids Suspended Tot.	Solids Suspended Vol.
Jul. 10	2075	-	-	-	-	-	-	-	-	-	-
17	4740	-	-	-	-	-	-	-	-	-	-
24	870	-	-	-	-	-	-	-	-	-	-
Aug. 3	2130	-	-	-	-	-	-	-	-	-	-
8	1040	-	-	-	-	-	-	-	-	-	-
22	965	-	-	-	-	-	-	-	-	-	-
Oct. 13	860	-	35	-	-	-	-	-	-	-	-
22	1335	-	55	-	-	-	-	-	-	-	-
Nov. 6	-	-	31	-	-	-	-	-	-	-	-

[1] Data incomplete because irrigation was discontinued.

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TABLE 4

Cation and Anion Analyses of Milk Wastes from Plant A

Date Collected	ppm K	ppm Na	ppm Ca	ppm Mg	ppm Chlorides	ppm P
8/3/56	68.0	102.5	-	51.0	133.0	-
8/24/56	118.0	216.0	46.0	31.6	278.4	6.48
10/13/56	44.0	176.0	92.0	60.4	-	19.5
10/16/56	26.2	138.0	86.0	50.0	128.0	15.6
11/6/56	33.2	198.4	78.0	55.0	180.0	27.0

APPENDIX

TABLE 5

Analytical Characteristics of Milk Waste from Plant B

1956	BOD	NH_3	TON	pH	Alk Tot	Alk HCO_3	COD	Solids Total Tot.	Solids Total Vol.	Solids Suspended Tot.	Solids Suspended Vol.
Aug. 3	3405	-	-	-	-	-	-	-	-	-	-
8	1980	-	-	-	-	-	-	-	-	-	-
22	-	-	-	-	-	-	-	-	-	-	-
Oct. 13	2230	-	128	-	-	-	-	-	-	-	-
22	2075	-	103	4.2	0	0	-	3450	-	-	-
Nov. 6	-	-	147	5.7	185	185	-	-	-	-	-
11	3945	-	126	4.8	93	93	-	4487	3033	-	-
20	4540	-	-	5.3	272	272	7276	5700	1017	648	500
28	4110	-	-	5.4	145	145	-	4772	2982	973	721
Dec. 5	4430	-	-	4.7	45	45	6362	6966	5638	-	-
11	-	-	-	4.6	0	0	7170	8378	6624	-	-
1957											
Jan. 3	-	-	-	-	-	-	-	4862	3783	-	-
Feb. 22	2880	76	152	4.9	154	154	3740	-	-	-	-
Mar. 13	6700	31	192	4.2	0	0	7260	9010	6850	1040	970
Mar. 28	9100	32	222	4.4	0	0	15320	11990	9988	-	-
Apr. 11	5750	20	140	4.3	0	0	-	7620	5070	1940	1840
May 24	4970	23	88	-	-	-	-	4140	2444	600	520

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TABLE 6

Cation and Anion Analysis of Milk Wastes from Plant B

Date Collected	ppm K	ppm Na	ppm Ca	ppm Mg	ppm Chlorides	ppm P
8/ 3/56	101.5	675.0	105.1	12.8	-	-
8/24/56	202.0	455.0	47.0	20.8	644.0	31.4
10/13/56	166.4	358.0	112.0	60.4	-	89.4
10/16/56	57.2	98.0	78.0	50.0	199.8	55.0
10/22/56	54.0	161.4	70.0	46.0	160.0	36.0
11/ 6/56	150.0	396.0	92.0	45.0	272.0	71.2
11/14/56	105.0	270.0	80.0	44.0	496.4	68.0
11/29/56	106.2	564.0	66.0	44.8	750.0	59.0
12/ 5/56	170.4	257.0	51.0	30.2	376.2	67.4
12/11/56	186.0	494.4	81.9	31.2	174.6	79.6
1/ 4/57	120.6	267.4	61.6	26.0	368.2	56.0
2/ 9/57	287.0	333.0	91.0	31.0	500.0	62.9
2/22/57	78.8	610.4	82.8	32.0	820.0	36.6
3/13/57	280.0	630.0	72.0	20.0	943.0	62.0
3/27/57	388.0	470,0	76.0	34.5	720.0	104.5
4/10/57	156.0	656.0	83.0	31.2	-	52.0
5/30/57	117.0	648.0	87.0	33.5	-	24.0

APPENDIX

TABLE 7

Analytical characteristics of Milk Wastes from Plant C

1956	BOD	NH_3	TON	pH	Alk		COD	Solids			
								Total		Suspended	
					Tot.	Bicarb.		Tot.	Vol.	Tot.	Vol.
Aug. 3	684	-	-	-	-	-	-	-	-	-	-
Aug. 8	722	-	-	-	-	-	-	-	-	-	-
Aug. 22	810	-	-	-	-	-	-	-	-	-	-
Oct. 22	735	-	19.2	7.0	264	264	-	2110	-	273	231
Nov. 6	-	-	9.1	6.5	235	235	-	-	-	-	-
Nov. 13	1090	-	-	7.5	278	278	-	2932	1106	-	-
Nov. 20	400	-	-	8.7	389	381	-	1406	365	-	-
Nov. 28	1510	-	-	6.1	149	149	-	-	-	723	447
Dec. 5	-	-	-	-	-	-	621	-	-	-	-
Dec. 11	-	-	-	6.8	334	334	-	-	-	-	-
Dec. 17	-	-	-	-	-	-	1380	-	-	-	-
1957											
Feb. 23	1620	16	66	5.6	163	163	1880	-	-	705	-
Mar. 13	-	31	-	4.1	-	-	-	-	-	1980	1720
Mar. 28	980	4	40	6.1	241	241	1370	2632	1078	340	-
Apr. 11	825	4	30	6.2	204	204	-	1638	916	260	252
June 20	-	8.4	80	4.2	-	-	-	8610	3720	1220	1220
July 3	790	0.4	27.8	6.6	257	257	890	1000	677	220	220
July 25	1200	2.5	28.2	8.4	346	342	1672	2212	1168	425	375
Sept. 6	450	0.9	21.1	6.6	270	270	-	-	-	-	-
Sept. 20	750	2.7	25.6	7.3	336	336	890	1640	930	310	300
Dec. 7	1470	1.0	48.0	4.9	20	20	-	2240	1340	360	286

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TABLE 8

Cation and Anion Analyses of Milk Wastes from Plant C

Date Collected	ppm K	ppm Na	ppm Ca	ppm Mg	ppm Chlorides	ppm P
8/24/56	31.4	245.0	43.6	30.2	260.0	-
10/16/56	14.4	183.0	70.0	35.0	185.6	14.0
11/ 6/56	62.0	468.0	94.0	60.0	606.0	36.8
11/14/56	18.6	430.0	84.0	42.0	904.0	26.0
11/20/56	12.0	274.0	43.6	30.0	252.0	27.7
11/29/56	24.8	620.0	76.4	51.6	844.0	39.0
12/11/56	19.0	619.6	70.6	31.8	636.0	34.4
2/ 9/57	26.0	394.0	-	30.4	616.0	24.6
2/22/57	31.2	732.0	89.4	34.4	1000.0	77.4
3/27/57	29.2	620.0	56.0	33.0	720.0	35.9
4/10/57	20.0	215.0	53.6	23.8	220.0	25.3
5/30/57	28.0	796.0	64.0	34.1	-	16.0
7/ 3/57	4.0	-	44.0	30.0	-	12.0
7/28/57	37	470.0	66.0	37.3	468.0	31.0

TABLE 9

Analytical Characteristics of Milk Wastes from Plant D

1956	BOD	NH_3	TON	pH	Alk		COD	Solids			
								Total		Suspended	
					Tot.	HCO_3		Tot.	Vol.	Tot.	Vol.
Oct. 13	4775	-	154	-	-	-	-	-	-	-	-
22	5940	-	185	5.2	202	202	-	7350	-	862	-
Nov. 6	-	-	110	6.5	376	376	-	-	-	-	-
13	4750	-	135	7.2	588	588	-	7068	5464	-	-
20	1849	-	-	7.1	461	461	1895	2726	749	564	488
28	4670	-	-	7.0	518	518	-	5609	4077	1323	1020
Dec. 5	2370	-	-	5.0	95	95	3009	3588	2474	-	-
11	-	-	-	6.4	320	320	2323	3576	2519	-	-
1957											
Feb. 22	4110	68.0	172	6.9	547	547	5380	-	-	785	-
Mar. 13	9440	9.0	212	4.4	0	0	-	8050	6250	1240	1140
Mar. 28	4330	4.0	140	4.6	112	112	5600	4558	3222	860	-
Apr. 11	8500	12.0	251	4.0	0	0	11,500	11,434	9404	1520	1520
May 24	-	63.5	143	-	-	-	1467	6140	4728	1800	1540
June 20	4780	1.1	124	4.6	230	230	-	4760	3090	1000	1000
July 3	3520	2.0	91.5	4.7	139	139	3370	3532	1940	510	510
July 18	4500	4.7	116.0	5.3	412	412	4603	4056	2670	980	960
July 25	3030	8.4	94.5	6.3	582	582	3576	3296	2096	980	900
Sept. 20	5350	21.8	183	5.6	440	440	6530	6100	4560	920	900

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TABLE 10

Cation and Anion Analyses of Milk Waste from Plant D

Date Collected	ppm K	ppm Na	ppm Ca	ppm Mg	ppm Chlorides	ppm P
10/16/56	30.8	222.0	74.0	48.0	144.0	72.0
10/22/56	129.0	365.0	100.0	35.0	276.0	156.0
11/ 6/56	57.6	240.0	84.0	40.8	104.0	124.0
11/14/56	132.6	386.0	72.0	35.0	170.0	188.8
11/20/56	30.0	274.0	42.8	29.2	-	135.2
11/29/56	127.6	422.6	64.8	47.4	224.0	180.0
12/ 5/56	57.4	317.2	54.8	32.2	156.6	108.7
12/11/56	45.8	330.0	60.6	29.6	710.0	123.9
1/ 4/57	58.2	320.0	50.6	22.3	106.0	84.4
2/ 9/57	162.0	282.0	102.0	31.0	120.0	194.3
2/22/57	105.6	330.0	84.0	30.8	190.0	146.0
3/13/57	305.0	480.0	72.0	20.0	420.0	161.0
3/27/57	87.6	453.0	98.0	26.0	280.0	131.3
4/10/57	319.4	642.0	100.0	53.0	442.0	162.8
5/30/57	452.0	416.0	101.0	140.0	-	32.5
7/ 3/57	102.0	504.0	56.0	30.0	350.0	116.0

APPENDIX

TABLE 11

Analytical Characteristics of Milk Wastes from Plant E

1956		BOD	NH_3	Total TON	pH	Alk		COD	Solids			
									Total		Suspended	
						Tot.	HCO_3		Tot.	Vol.	Tot.	Vol.
Oct.	22	570	-	31	7.8	418	418	-	-	-	-	-
Nov.	6	-	-	17	7.1	544	544	-	-	-	-	-
Nov.	13	930	-	-	7.0	490	490	-	1421	739	-	-
	20	1594	-	-	6.9	766	766	-	2796	1144	502	390
	28	1380	-	-	-	-	-	-	2565	1743	-	-
Dec.	5	1160	-	-	6.8	522	522	-	2362	1006	-	-
	11	-	-	-	4.6	0	0	2830	3326	2332	-	-
1957												
Feb.	22	1560	40	68	6.5	357	357	1920	-	-	284	-
Mar.	13	2220	16	66	5.5	238	238	2720	3144	2346	273	260
	28	1900	4	64	5.4	670	670	2245	2614	1726	380	-
Apr.	11	1660	2	70	5.8	323	323	-	2566	1638	380	380
May	24	1400	-	-	-	-	-	-	1472	668	500	260
June	20	1260	10	30	6.8	486	486	1100	2090	1240	374	340
Jul.	3	1590	25	-	6.8	480	480	1595	2044	1290	380	327
	18	510	-	-	7.6	374	374	665	1208	554	300	294
Sept.	6	490	4	26	8.0	860	860	-	-	-	-	-
	20	435	2	20	9.5	1088	-	552	2028	1008	273	200
Dec.	6	1790	28	41	6.7	464	464	-	2340	1480	324	283

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TABLE 12

Cation and Anion Analyses of Milk Wastes from Plant E

Date Collected	ppm K	ppm Na	ppm Ca	ppm Mg	ppm Chlorides	ppm P
10/16/56	22.0	201.0	68.0	42.0	57.4	28.0
11/ 6/56	34.6	-	70.0	45.0	-	16.0
11/14/56	16.2	193.0	58.0	45.0	100.0	36.0
11/20/56	42.0	219.2	56.8	32.0	164.0	29.5
11/29/56	46.4	225.6	46.8	44.8	130.0	38.6
12/ 5/56	53.6	236.0	50.4	32.8	244.8	34.6
12/11/56	61.2	320.4	54.2	29.2	198.4	62.0
2/ 9/57	146.8	314.0	-	49.2	354.0	43.4
2/22/57	32.0	168.0	106.8	30.8	140.0	29.2
3/27/57	54.0	310.0	44.0	29.0	120.0	44.3
4/10/57	46.0	329.0	44.0	19.2	133.0	46.0
5/30/57	19.2	288.0	64.0	35.0	-	16.0
7/ 3/57	32.0	260.0	32.0	29.6	-	34.0
7/18/57	-	-	-	-	240.0	-

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